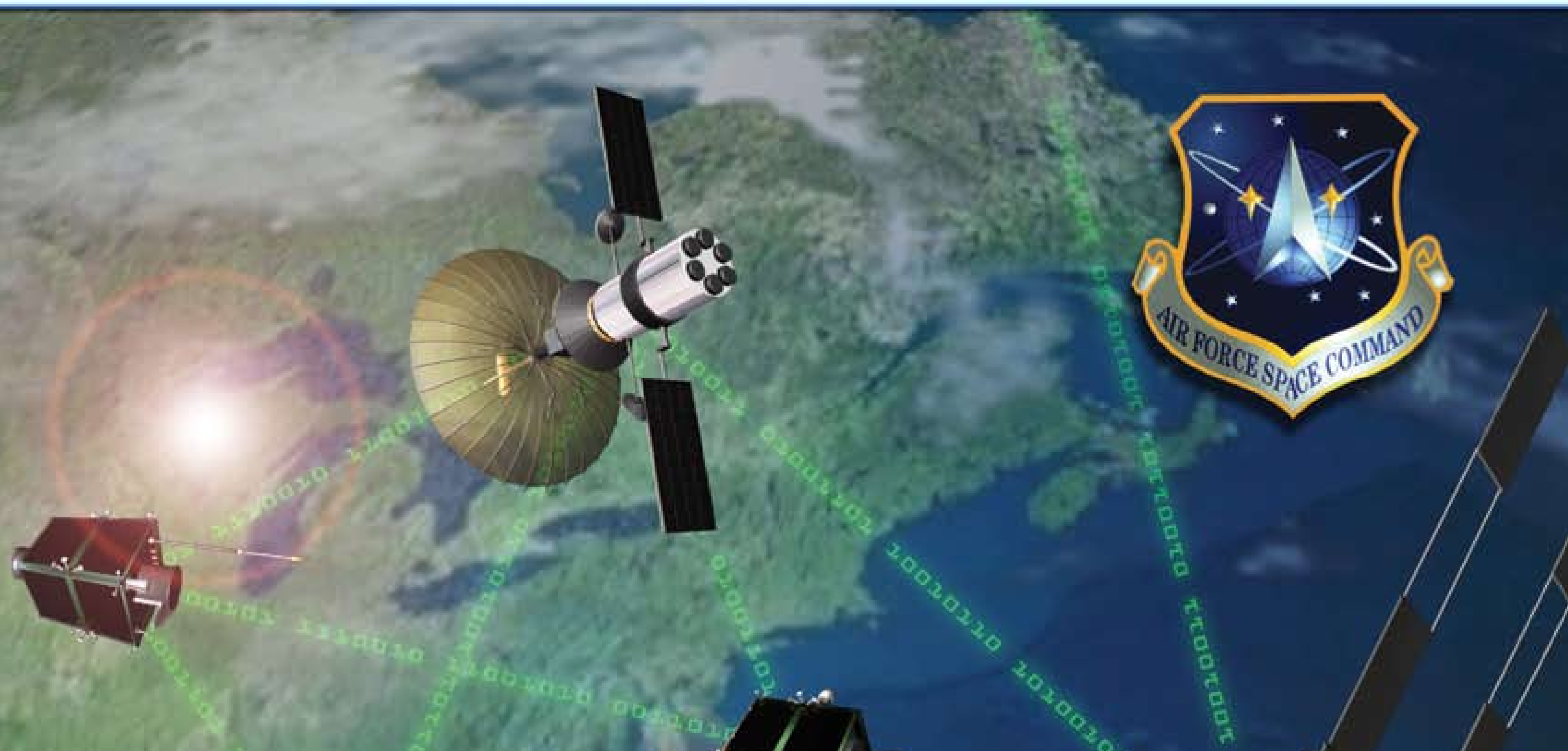
AIR FORCE SPACE COMMAND

Volume 5, Number 1

HIGH FRONTIER

THE JOURNAL FOR SPACE & MISSILE PROFESSIONALS



INSIDE:

The Challenge of Protecting Space Capabilities

Action-based Approach for Space Protection

Components of a Space Assurance Strategy

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **NOV 2008**	2. REPORT TYPE	3. DATES COVERED **00-00-2008 to 00-00-2008**

4. TITLE AND SUBTITLE **High Frontier, The Journal for Space & Missile Professionals. Volume 5, Number 1, November 2008**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Air Force Space Command (AFSPC),150 Vandenberg St. Ste 1105,Petereson AFB,CO,80914**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**56**	

Headquarters
Air Force
Space Command
Peterson Air Force Base, Colorado

Commander
General C. Robert Kehler

Vice Commander
Maj Gen Thomas F. Deppe

Director of Public Affairs
Col Dewey Ford

Creative Editor
Ms. Nadine Sage

High Frontier Staff

Mr. Steve Tindell
Dr. Corvin Connolly
Dr. Rick Sturdevant
Maj Audrey Pfingston
Maj Kirstin Reimann
Maj Frank Zane
MSgt Jennifer Thibault

Editorial content is edited, prepared, and provided by the *High Frontier* staff. All photographs are Air Force photographs unless otherwise indicated.

High Frontier, Air Force Space Command's space professional journal, is published quarterly. The journal provides a scholarly forum for professionals to exchange knowledge and ideas on space-related issues throughout the space community. The journal focuses primarily on Air Force and Department of Defense space programs; however, the *High Frontier* staff welcomes submissions from within the space community. Comments, inquiries, and article submissions should be sent to AFSPC.PAI@peterson.af.mil. They can also be mailed to:

AFSPC/PA
150 Vandenberg St. Ste 1105
Peterson AFB, CO 80914
Telephone: (719) 554-3731
Fax: (719) 554-6013

For more information on space professional development please visit:
http://www.afspc.af.mil

To subscribe:
Hard copy: nsage@colsa.com
Digital copy: http://www.af.mil/subscribe

Cover: Artist's concept of a fractionated satellite cluster operating cooperatively and autonomously using a wireless network in space. Artist: Alexander Bradley, Organization: DARPA.

Back Cover: Space Debris. Image courtesy of Analytical Graphics, Inc.

HIGH FRONTIER

The Journal for Space & Missile Professionals

November 2008 Volume 5, Number 1

Contents

Next Issue: ***50th Anniversary — ICBM***

Introduction

General C. Robert Kehler
Commander, Air Force Space Command

"The United States national security is critically dependent upon space capabilities and this dependence will grow."
~ National Security Presidential Directive - 49,
US National Space Policy, August 2006

The last 50 years of sovereign space exploration and exploitation have proved invaluable to the continued success of our military, allies, and nation. As we look forward to the next 50 years there are significant developments which shape how we preserve our sovereignty and freedom of action within the space domain. In response, Headquarters, Air Force Space Command (HQ AFSPC) and the National Reconnaissance Office established a joint Space Protection Program (SPP). The SPP is an enduring joint activity empowered to provide decision makers with a range of informed options and recommendations on how best to preserve our space systems, through collaborative efforts across the Department of Defense and Intelligence Communities (IC). This quarter's *High Frontier* compiles perspectives on space protection highlighting the urgency, the impacts, and future challenges. Past, current, and future senior leaders from the US House of Representatives, industry, academia, defense agencies, USSTRATCOM, and HQ AFSPC offer their perspectives, share their personal experiences, and highlight some challenges as we look toward the future.

The first of three articles in the "Senior Leader Perspective" section begins with US Representative Terry Everett, as he elaborates on his beliefs that the space domain is no longer a sanctuary, which we need to put "First Things First" in space acquisition and build a cadre of space professionals. Next, Dr. Andrew Palowitch, director, Space Protection Program, provides insight into the strategy development process for a comprehensive SPP. The Senior Leader Perspective concludes with Dr. Wanda M. Austin, president and CEO of The Aerospace Corporation, as she provides her reflections on the challenging array of protecting space capabilities.

Progressing through this quarter's volume, we provide five articles on Space Protection. Maj Patrick Brown leads this section with a discussion on the importance of transparency through joint collaboration and international partnerships and how this could lead to enhanced satellite safety. Mr. Samuel Black proposes a space assurance strategy which focuses on diplomacy and purely defensive measures to provide for space assurance. Third, Col Lee W. Rosen and Lt Col Carol P. Welsch focus on satellite self-protection and the concrete first steps that must be taken to protect the next generation of satellites. Next, Maj Wallace Turnbull proposes an attribution architecture for space control which establishes a solid foundation upon which national leaders can build a viable space policy. The fifth and final article in the Space Protection section is authored by Mr. Naresh Shah and Dr. Owen Brown. They propose fractionalization as an approach in which modern technologies are used to decompose large systems into smaller physical elements.

In the "Industry Perspective" section, we present two articles; first, Mr. Phillip Bowen and Mr. Clifton Spier bring forward a proven systems engineering approach to decomposing the Space Situational Awareness mission area into key functional attributes predicated upon the country's need for space protection capabilities. Second, Mr. Steven Prebeck and Mr. Kenneth Chisolm deliver an alternative approach to tackling the SPP problem by starting at the end state and reversing the process to determine actions required to create the desired outcome.

In this edition's "Warfighter Focus" section, Lt Col Stuart Pettis provides his personal experiences as an air liaison officer and provides recommendations for integrating Air Force space operators into Army tactical level operations.

In the "Professional Development" section, Lt Col Rob Vercher and Andrew Kovich encourage individuals who study the art of leadership to view this dynamic and complex subject through the lens of two characters in Anton Meyer's novel, "Once an Eagle."

We conclude this quarter's volume with a book review by Lt Col David Arnold, entitled "Space as a Strategic Asset."

As with all issues of the *High Frontier*, I hope you are leveraging this magazine to expand your personal and professional horizons. We are clearly in the midst of interesting times and since we get paid to deal with interesting times, I look forward to your articles on the next volume's topic, "50th Anniversary — ICBM." As we navigate through the decisions from the Fall CORONA 2008, I encourage you to think about the nuclear enterprise and the implications of a new command, how best we can make the transition, how it impacts the mission, the people, and how it contributes to strategic deterrence.

General C. Robert "Bob" Kehler (BS, Education, Pennsylvania State University; MS, Public Administration, University of Oklahoma; MA, National Security and Strategic Studies, Naval War College, Newport, Rhode Island) is commander, Air Force Space Command (AFSPC), Peterson AFB, Colorado. He is responsible for the development, acquisition, and operation of the Air Force's space and missile systems. The general oversees a global network of satellite command and control, communications, missile warning and launch facilities, and ensures the combat readiness of America's intercontinental ballistic missile force. He leads more than 39,700 space professionals who provide combat forces and capabilities to North American Aerospace Defense Command and US Strategic Command (USSTRATCOM). General Kehler will assume cyberspace responisiblities as directed by CORONA Fall.

General Kehler has commanded at the squadron, group, and twice at the wing level, and has a broad range of operational and command tours in ICBM operations, space launch, space operations, missile warning, and space control. The general has served on the AFSPC Staff, Air Staff, and Joint Staff and served as the director of the National Security Space Office. Prior to assuming his current position, General Kehler was the deputy commander, USSTRATCOM, where he helped provide the president and secretary of defense with a broad range of strategic capabilities and options for the joint warfighter through several diverse mission areas, including space operations, integrated missile defense, computer network operations, and global strike.

Work Worth Doing

US Representative Terry Everett
Ranking Member, Subcommittee on Strategic Forces
House Armed Services Committee
Washington, DC

"Far and away the best prize that life has to offer is the chance to work hard at work worth doing."

~ Theodore Roosevelt

My 16 years in the US House of Representatives have been tremendous. It has been an honor to serve the great people of the state of Alabama and a privilege to work with this community of dedicated professionals to enhance our nation's strategic forces capabilities. As I near the end of my tenure as a member of Congress, I would like to take the opportunity to share my assessment of the strategic forces portfolio—in particular the state of national security space—and discuss our future challenges.

Educating Congress and the American Public

Often, members of Congress come to me during debates on space-related issues and ask for my views and recommendations. They have a genuine interest in the topic, but lack an in-depth appreciation of how truly vital space has become. I think the American public is in a similar position, generally supportive of our investment in space but largely unaware of how essential the capabilities and services provided by satellites are to our national security, economy, and modern way of life.

When it comes to national security, my colleagues have a general sense that space capabilities are important to military operations, but I am not sure they realize how truly integral they are to the way we fight. I like to explain that the aircraft, naval vessels, and land vehicles they support and fund simply can not be effective without the communications, navigation, and other services provided by our space capabilities. Retired Army General Larry Dogden tells one of my favorite stories. He once asked a soldier if he uses space; the soldier replied "no," I just need this black box to talk to my commander and tell me where I am.

We have witnessed tremendous growth in commercial and civil uses of space; growth that was not imagined 16 years ago. On the commercial side, a 2007 Space Foundation report highlighted that the global space industry grew to nearly $220 billion; an 18 percent increase in a two-year time span. Commercial aviation, shipping, emergency services, in-vehicle navigation, vehicle fleet tracking, and ATM and financial transactions have come to rely on services from space.[1] Agriculture, which is a prominent industry in my home state, has benefited from the application of the Global Positioning System (GPS) and satellite imagery to track farm equipment, assess crop health, and forecast crop production.[2] Most recently, quick damage assessments and survivor search and rescue from Hurricane Ike were made with support from Global Hawk unmanned aerial vehicles connected via satellites.[3]

Educating others to understand the importance of space—the "so what"—and why we must continue to support these capabilities will remain a continuing challenge for our community. Another challenge will be ensuring we maintain our access to these capabilities. I have focused much of my energy on raising awareness at a national level, though admittedly, in small steps by leveraging legislative vehicles and the print media. In June 2006, I held a Strategic Forces subcommittee hearing to broaden understanding of our military and economic dependence on space. The 2007 defense bill included language tasking the National Space Studies Center at Maxwell AFB's Air University to examine our nation's economic and military dependence on space and the implications were we to lose these capabilities.[4] We have only begun this important conversation and education with the Congress and American public, and must continue the effort.

Establishing Greater Space Protection and Space Situational Awareness

I strongly hold to the belief that space is no longer a sanctuary. What has become increasingly clear over the last several years is the need for greater space situational awareness (SSA) and protection of our space assets. Senior administration officials did not share my same sense of urgency, nor did I see much cooperation across the defense and intelligence communities to mitigate our collective vulnerabilities. The January

Everett-Hunter press conference picture with caption, "Representative Terry Everett with Representative Duncan Hunter of California calling on the president to strengthen our space protection capabilities, 31 January 2007."

2007 Chinese anti-satellite (ASAT) test was a strong wake-up call for Congress and the administration, but was merely the tip of an iceberg of counterspace threats that continue to grow below the surface.

A greater emphasis on addressing our space vulnerabilities was clearly needed. Therefore, in a bipartisan manner, Representative Ellen Tauscher of California, chairman of the Strategic Forces subcommittee, and I sponsored legislation in the 2008 National Defense Authorization Act directing the secretary of defense and director of National Intelligence to develop a comprehensive space protection strategy.[5] I am encouraged by the actions and progress they have made to-date. Last year we saw Air Force Space Command (AFSPC) and the National Reconnaissance Office (NRO) integrate their space operations centers' activities. This past August, the defense and intelligence chiefs delivered their joint space protection strategy to Congress. Equally significant was the establishment of the Space Protection Program, jointly led by AFPSC and NRO. As I understand it, this body will examine our space architecture, looking across the spectrum of technology, operations, and programmatics, to identify near-term and future opportunities to enhance space protection and mission assurance.

The real test of putting this strategy into action still lies ahead of us. I would like to see the community incorporate the strategy into their overall investment portfolio, which includes influencing concrete program and budget decisions. I also believe we must strengthen the requirements and acquisition processes to ensure protection is considered during key milestone reviews. This may result in changes to the capabilities currently being pursued, schedules, and funding profiles. Less than four percent of the "white space" budget is allocated to SSA and space protection. In a welcome move, this has increased over the last year. However, in 2008, several key SSA initiatives, such as the Self-Awareness SSA System, Rapid Attack Identification Detection and Reporting System, and the Space Fence, ended up on the Air Force unfunded priority list. Will we see action follow words?

As a former intelligence analyst, I have a deep appreciation for the complexities of intelligence. Our space intelligence community does an excellent job with the little information they have, particularly the National Air and Space Intelligence Center and Missile and Space Intelligence Center. However, future space conflicts will demand real-time intelligence and attribution that rest on greater foundational intelligence and tighter linkages between operations and intelligence. This capability will only come with a commitment to long-term investments in SSA and intelligence collection capabilities, analytical tools, and the cultivation and retention of experienced analysts.

One of the most challenging dimensions of space protection is policy, specifically how we respond to future space conflicts or interference events. I have been particularly focused on space deterrence and escalation management. We have witnessed ASAT tests, laser dazzling, and jamming incidents, yet we don't seem to have clear policy "red lines" for attacks against our satellites, clear decision-making processes, or established response options. This year, I successfully included language in the House-passed version of the defense bill to explore these issues through Department of Defense (DoD) wargames and exercises that together will improve our military and policymakers' preparedness to cope with future conflicts in space.[6]

As China's ASAT test and our own satellite intercept mission last February demonstrated, any future space incident will require a "whole of government" approach, leveraging political, military, intelligence, diplomatic, legal, economic, and strategic communications tools. I recently participated in a seminar with senior space leaders to discuss these issues. I was pleased to see such a broad swath of government, academia, and foreign partners tackling these important policy issues.

Putting 'First Things First' in Space Acquisition

Another topic I have found incredibly challenging is space acquisition. Oversight of space acquisition programs demands a level of technical knowledge most members of Congress simply do not have. We instead focus on simple metrics—performance, cost, schedule, and risk. However, these simple metrics have painted a fairly accurate and bleak picture of space acquisition.

The recapitalization and modernization of our space portfolio has placed great strain on the acquisition community and the space budget. We have seen symptoms of this strain in Nunn-McCurdy breaches for Space-Based Infrared System (SBIRS)-High and National Polar-orbiting Operational Environmental Satellite System, schedule delays to the GPS-IIF and Advanced Extremely High Frequency satellite programs, and the program restructuring of Transformational Satellite Communications System and Space Radar. Balancing recapitalization and modernization, and the affordability of both, is perhaps the most taxing aspect of managing and overseeing the national security space portfolio.

One way to alleviate the strain is to increase the space topline, which I have long advocated. But short of that, the community has some tough decisions ahead of it. Without a significant increase to the space budget or realignment of recapitalization and modernization programs, the space portfolio will become unaffordable and unexecutable.

I have previously written about the need for government and industry to improve cost estimating, strengthen systems engineering and quality control, limit requirements growth, more closely manage the prime-subcontractor relationship, and rebuild our nation's cadre of space acquisition and cost estimat-

As China's ASAT test and our own satellite intercept mission last February demonstrated, any future space incident will require a "whole of government" approach, leveraging political, military, intelligence, diplomatic, legal, economic, and strategic communications tools.

I know opinions in Congress vary. However, I believe one person setting policy and making planning, acquisition, and resource decisions in the context of an integrated architecture better serves our national security and reduces unnecessary overlaps.

ing professionals. I could probably go on, but fundamentally it highlights the necessity of becoming a "smarter buyer" and upholding the basic tenets of leadership, discipline, and accountability. We must have the leadership to make tough decisions, and to say 'no' on occasion. We must be smarter in acknowledging not every requirement is affordable, smarter not to be fooled by budgets that do not close, smarter in recognizing proposals that are underbid, smarter in understanding risk, and more disciplined in holding to these stances. Lastly, we must hold ourselves accountable for both the good and the bad. I say 'we' because Congress is as much a part of the problem and solution as the executive branch and industry.

I believe the "Back-to-Basics" acquisition approach instituted by former Air Force Undersecretary Ronald M. Sega is sound; it is similar to my "First-Things-First" philosophy. There are small signs that the community has turned the corner; however, we won't know for sure until the current and next generation of satellites are launched, and the final tallies on cost and schedule are completed.

With concerns about vulnerabilities and single-point failures, we must also change the legacy model of building a few large, expensive, complex satellites. One area of potential promise is Operationally Responsive Space (ORS). Our intent, codified in 2007 legislation, was to focus on getting simple, low cost solutions rapidly on-orbit to meet the urgent needs of our combatant commanders. Secondarily, ORS would provide more frequent opportunities to demonstrate innovative concepts and technologies at a lower cost, while energizing our industrial base and technical workforce. With this effort, I see a stronger national security space portfolio in which ORS systems complement, not replace, traditional space programs.

While ORS has much promise in getting us to a more numerous, distributed architecture in space, it is still a nascent capability. It has been in existence barely a year—a flash in satellite acquisition time. We must give it time to mature; it will take time to invest in technology and system development, to develop new thinking on employment and operating concept, to adapt government and industry to this new paradigm, and time to make ORS successful and transition these successes to the rest of our space architecture.

Resisting the "Rice bowl" and Creating the Right Teamwork Incentives

A great disappointment has been witnessing firsthand the extent to which "rice bowls" dominate decisions on space programs. To illustrate this point, I have seen the defense and intelligence establishments take over a year to make a decision on a space-based military intelligence system while they argued over what to buy and who should buy it. Supposedly this was an urgent need. The loser in all this is the soldier on the ground who relies on this capability being there when needed.

I do not see any incentives for the community to work together. The current reward structure is based on an organization's ability to protect its budget and control programs. It is unfortunate that we don't have "customer satisfaction surveys" for space. I think a key improvement a new administration could introduce is a reformed incentive structure that rewards teamwork and cross community collaboration.

Similarly, the understood, clear lines of leadership in national security space have become a tangle of "spaghetti" line charts. For example, questions about space acquisition bring answers from no less than four offices. Last October, I sent a letter to Defense Secretary Robert M. Gates asking him to re-establish the dual-hatted undersecretary of the Air Force and director of the NRO position. These offices have been split since 2005, primarily due to concerns that one leader could not effectively manage both the Air Force and NRO space portfolio. I fail to understand why one person cannot provide oversight and leadership across national security space. The secretary of defense has the entire defense portfolio under him.

I know opinions in Congress vary. However, I believe one person setting policy and making planning, acquisition, and resource decisions in the context of an integrated architecture better serves our national security and reduces unnecessary overlaps. The next Congress and new administration will have an opportunity to review this concern as well as other space organization and management issues, particularly with the completion of the congressionally mandated national security space organization and management review, led by Mr. A. Thomas Young, a respected space authority and former Lockheed Martin executive.

Building a Cadre of Professionals

Lastly, I want to touch on an area that is important to me—professional development and science and math education.

The nucleus of our space efforts—our nation's space cadre—has weakened over time. We have seen a reduction in the number of trained, experienced government space acquisition, science and engineering, and program management professionals. Those remaining have become increasingly reliant on industry without having the wherewithal to provide experienced leadership or question technical findings. We need to break this pattern and foster a space cadre of smarter, more empowered professionals who know the technical, operational and programmatic aspects of their acquisition programs.

I sponsored legislation last year that required the secretary of defense to submit a report to Congress on the management of the space cadre within the DoD. I commend efforts by the military departments to expand their space professional development activities, to include increased education and training

Without an assessment of space cadre requirements and the development and use of metrics, I believe it will be difficult to track progress in ensuring the DoD has sufficient numbers of personnel with the expertise, training, experience, and leadership to meet current and future national security space needs.

opportunities, establishment of space-related specialty codes, and development of personnel databases. However, as noted in a September 2006 Government Accountability Office report, management actions are needed to better identify, track, and train Air Force space personnel. This is an issue broader than the Air Force. Without an assessment of space cadre requirements and the development and use of metrics, I believe it will be difficult to track progress in ensuring the DoD has sufficient numbers of personnel with the expertise, training, experience, and leadership to meet current and future national security space needs.

I am also interested in ideas on how to strengthen youth science and math education, and recruit more young folks into aerospace careers. I wish I had a simple solution for this. I sense today's youth are naturally fascinated by space and space exploration. However, without conscious long-term efforts to attract young individuals to the field as well as providing them motivating and rewarding work, to retain them, I fear that we will put at risk our leadership in space science and technology, the health of our industrial base, and our nation's overall leadership in space.

Final Thoughts

I am incredibly thankful to the national security space community, and particularly the men and women of the US Air Force for their service, dedication, and sacrifice. During my tenure on the Strategic Forces subcommittee, I have had the good fortune to visit key Air Force facilities, operations cells, and industry centers of excellence. I am grateful to the many hard-working airmen, industry representatives, and senior leaders who have briefed me over the years, hosted me during site visits, and taken the time to educate me on these important matters of national security.

Space is one of the most unique, challenging, and exciting things our nation does. We have challenging space policy and program issues ahead of us and collectively, I have confidence that we will work through them. I am proud to be associated with our nation's space efforts and with the people who make them happen. This has been and will continue to be work worth doing.

Notes:

[1] "The Space Report: The Guide to Global Space Activity," Executive Summary, The Space Foundation, 2007 update.

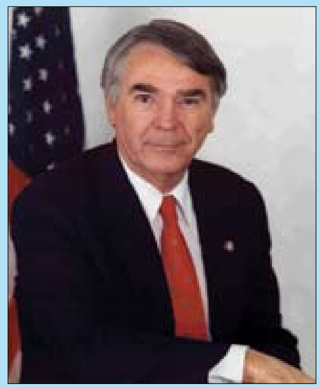
[2] *Southeast Farm Press*, December 2007, http://southeastfarmpress.com, 2, 12, 17, 29.

[3] Geoff Fein, "Global Hawk Provides Imagery In Ike's Aftermath," *Defense Daily*, 16 September 2008.

[4] Fiscal Year 2007 National Defense Authorization Act, Report of the Committee on Armed Services, House of Representatives, on H. R. 5122, Report 109-452, 298.

[5] Fiscal Year 2008 National Defense Authorization Act, Section 911 (Public Law 110-181; 122 Stat 279).

[6] Fiscal Year 2009 National Defense Authorization Act, Report of the Committee on Armed Services, House of Representatives, on H. R. 5658, Report 110-652, 339.



US Representative Terry Everett (R-Alabama) Eight-term Republican congressman from the Second Congressional District of Alabama from 1993-present. Ranking member, Strategic Forces Subcommittee, House Armed Services Committee. He served in the United States Air Force from 1955-59 as an intelligence specialist. Stateside, he pursued a three decade career in journalism culminating in the ownership of a chain of newspapers in south Alabama. In Congress, Everett also serves as the second ranking member on the House Permanent Select Committee on Intelligence and the House Agriculture Committee. In 1998, Congressman Everett received the "Excellence in Programmatic Oversight Award" from the House Republican Leadership for his Veterans' Affairs Subcommittee probe into improper burial waivers at Arlington National Cemetery. In 2004, Everett became the first chairman of the newly-created House Armed Services Subcommittee on Strategic Forces, overseeing the subcommittee until 2007. Congressman Everett's efforts as chairman and ranking member have focused on improving space acquisition programs and beginning a national debate on space. Congressman Everett has spearheaded key legislative initiatives in national security space, including development of a space protection strategy, management of the space cadre and space acquisition personnel, and establishment of the Operationally Responsive Space Office. During his tenure as chairman of the Strategic Forces subcommittee, he held frequent hearings and classified briefings on national security space issues, including space control, threats, and acquisition challenges, and space radar, space cadre, and space policy. He has also labored to maintain proper funding for important space acquisition programs and initiatives, such as space radar, Transformational Satellite Communications System, and the National Space Studies Center. In October 2006, Congressman Everett was honored by the Missile Defense Advocacy Alliance for his work in support of missile defense overall and in particular funding for the research and development of the Theater High Altitude Area Defense missile system. In September 2008, he was presented the National Nuclear Security Administration's (NNSA) Gold Medal for support of the NNSA.

First Steps Towards a Strategic Position

Dr. Andrew W. Palowitch
Director, Space Protection Program
Peterson AFB, Colorado / Chantilly, Virginia

Survivability has always been a primary design objective for satellite programs. Inaccessibility for repair and natural space hazards have necessitated the incorporation of protective hardware measures such as shielding and circuit redundancy. This historic approach to satellite survivability has evolved dramatically driven by man-made space hazards and the development of counter-space systems. But, independent of a space hazard analysis, the need for satellite survivability has also taken on a new level of importance with considerations from a different point of view.

First, we, as individuals have developed a fundamental reliance on space systems for everyday activities including communications, personal banking, weather forecasting, and navigating our cars. We keep increasing our demands for improved continuity of service and new capabilities. Commercial providers are constantly expanding the space-derived products and services market with new options to buy commercial imagery for personal use or to employ tracking systems to find errant children and pets. Second, but more importantly, we, as an international community with over 80 space-faring nations flying thousands of satellites, have linked our future for continued global economic prosperity, national security, and safety directly on our now highly interconnected set of space systems that we have collectively established.

Recognition and appreciation of these factors necessitate a new approach in space protection. We, speaking as the international community again, long ago transcended the value of solely focusing on the protection of individual satellites and have moved to the need for protection of global space system effects. However, all the necessary institutions and arrangements have not kept pace with this transition from individual satellite focus to interdependent system reliance. International policy, law, agreements, and cooperative ventures addressing protection have yet to be considered – much less put into effective operation. Despite the challenge in the international scene, on a national level progress is being made. The Pentagon has initiated bilateral discussions with several nations. And the nation's first comprehensive space protection strategy was developed and accepted this year by national leadership. The strategy addresses all military, intelligence, civil, commercial, and allied space effects important to US national security under a comprehensive protection approach.

Strategy ➔ Program ➔ Results

Throughout the early months of this year an integrated team of defense, intelligence and state participants worked on the fundamental principles of a comprehensive space protection strategy. During their strategy development process dimensions of the protection problem were examined which widened the scope significantly from what could have been just a limited set of military defensive approaches. Elements of the proposed strategy covered aspects of protection from situational awareness through assurance that important space effects could be maintained to support national interests. In late July the Space Protection Strategy was approved by the Department of Defense (DoD). It was subsequently forwarded to Congress as part of a Congressionally Directed Action response to the Fiscal Year 2008 National Defense Authorization Act.

In the report that accompanied the Strategy to Congress was a reference to a newly formed organization, the Space Protection Program (SPP), and a description of its central role in the execution of the newly developed strategy. The SPP was officially established on 31 March 2008 as a joint National Reconnaissance Office (NRO) and Air Force Space Command (AFSPC) effort to provide "decision-makers with strategic recommendations on how best to protect space systems." General C. Robert Kehler, commander AFSPC, and Mr. Scott Large, director, NRO (DNRO) signed into effect the SPP mission to "preserve national security space effects through an integrated strategy and to articulate vulnerabilities, assess threat impacts, identify options, and recommend solutions leading to comprehensive space protection capabilities." Their vision was to consolidate all stakeholders protection initiatives and requirements under a central national strategy and better leverage everyone's resources to maximize the return on our collective investments in space.

The SPP employs a small highly specialized cadre of USAF and NRO space professionals to execute its mission. Initial collaborative efforts have leveraged, by design, the previous work and resources of the Space and Missile Command, the Defense Advanced Research Projects Agency, the National Security Space Office, and various US Air Force Program Offices. Close coordination has been maintained with DoD acquisition, intelligence, and policy organizations, with the director of National Intelligence's interests, and with the National Security Council staff. Interactions with other US government agencies and commercial companies have been extensive fulfilling the DNRO's desire for a "holistic approach that leverages the strengths of the entire space community." It has been all to easy over recent years to criticize the state of the US space community—it's personnel, technical depth, readiness, and organizational structure. But as is evident from continued achievements collectively it is still by far the best in the world.

US Representative Terry Everett recognizes the challenge of putting strategy into action and has challenged the space community to incorporate protection strategy into acquisition decisions to enhance the stability of our national infrastructure. In its first efforts along these lines and in conjunction with the SPP

Espousing altruistic ideals for peaceful cooperation in space among space-faring nations and implementing well designed protection activities may provide a sound framework upon which to build national or international space protection programs. However ...

charter to develop a technically-based long-term implementation of the strategy, the SPP has been called to provide 'real-time' support for space program decision-makers. SPP Deputy Director for Technology, Dr. Stewart Cameron, drawing upon the strength of the NRO's Assessment and Engineering Office staff is supporting several NRO acquisition programs. In a similar fashion, SPP Deputy Director for Strategy, Col Joseph Squatrito, USAF, and his staff are supporting several pressing US Air Force mission areas. This is a start. The long term goal of centrality of space protection guidance within the entire space community will serve the nation well by connecting previously disconnected short-term program decisions under a common approach which serves the larger national strategy.

Protection Challenges

Far from being easily achieved, the implementation of specific cooperative space protection actions—even if you have the right answer—faces both internal and external challenges. No US government programs are ever free from the complex web of internal political and budget pressures, conflicting requirements, and organizational sensitivities. But more serious are the pressures from external forces including the political and military intentions of other nations, the difficulty of working in the space environment without common internationally accepted guidelines, and the potential misperception of the motive behind well-intentioned actions.

Further, the complexity of potential protection options raises the question "How do you know you have the right answer in the first place?" Potential options to maintain national space effects cover the gamut from defensive hardware built into next generation satellites to investing in rapid replenishment capabilities to restore capability after loss. A rigorous repeatable analytical process must underlie all proposed comprehensive protection schemes. Interestingly among the possible options, two enduring protection themes bear continued work independent of all other pursuits. First is to reduce man-made hazards in space and threats to space systems—which includes debris creating events. Second is to achieve comprehensive space situational awareness focused on identifying hazards, ascertaining intent, and attributing actions.

Espousing altruistic ideals for peaceful cooperation in space among space-faring nations and implementing well designed protection activities may provide a sound framework upon which to build national or international space protection programs. However, rogue actors with little or no dependency upon or investment in space systems carrying out asymmetric actions point out the fallacy of relying on this approach exclusively. The US policy for free access to and use of outer space by all nations for peaceful purposes is thoughtfully balanced by our National Space Policy position that freedom of action must be maintained by the flexibility to protect our national security interests.

Towards a Greater Good

Our future for continued global economic prosperity, security, and safety is linked inextricably to the capabilities we derive from space systems. It is time to achieve a level of protection for those systems commensurate to the threat we project to their survivability—but more importantly to the value we derive as a global community from those capabilities.

Andrew W. Palowitch, PhD (BS, Mechanical Engineering, United States Naval Academy, Annapolis, Maryland; MS and PhD, Bio-Optics, University of California at San Diego; MA, International Relations, Tufts - Fletcher School of Law and Diplomacy) is the founding director of the Space Protection Program. Prior to assuming this role, Dr. Palowitch was the chief technology officer for the Intelligence, Security and Technology Group, Science Applications International Corporation (SAIC) and a SAIC Technical Fellow. He provided advanced scientific solutions and systems engineering approaches to solve the nation's most difficult intelligence, defense, and homeland security problems.

From 2002 to 2005, Dr. Palowitch was the director of the CIA's Systems Engineering and Acquisition Office and the director of DCI Systems Engineering Center. In these positions he developed systems solutions, guided collection system acquisition, and led operations to guarantee global assured clandestine technical access. He led intelligence community systems engineering activities under direction of the DCI.

From 1998 to 2002, Dr. Palowitch was the chairman and chief executive officer of Dynamics Technology, Inc. He directed physics-based sensor modeling, simulation, and analysis on complex intelligence and defense systems. Dr. Palowitch concurrently managed technical evaluation of DynaFund's international venture capital investments to acquire breakthrough technology.

Previously, from 1996 to 1998, Dr. Palowitch served as the chairman and chief executive officer of Energy Compression Research Corporation, located in San Diego, California. In this position he designed, developed, and manufactured revolutionary light-activated-silicon-switches for advanced defense pulsed power systems and commercial high power electrical distribution systems.

Dr. Palowitch's additional education includes: Senior Executives in National and International Security, Harvard JFK School of Government, 2004; US Government Intelligence Fellows Program, 2003; and Executive MBA Program, Stanford University, 1998 and 2001.

Dr. Palowitch served as a United States Navy Submarine Officer onboard the Presidential Unit Citation awarded USS Parche, SSN 683, from 1982 to 1987.

The Challenge of Protecting Space Capabilities

Dr. Wanda M. Austin
President and CEO
The Aerospace Corporation
El Segundo, California

Over the past half century, the development, operation, and utilization of space systems have matured to deliver capabilities that today underpin US economic, technical, and military leadership. Space systems provide us with essential global services in the areas of communications, navigation, weather, intelligence, surveillance, and reconnaissance, and also provide an important venue for space exploration and scientific research. Awareness of the vital role of space capabilities in our economy and national security has grown in recent years due in part to the well-publicized capabilities provided to the military and the public by the Global Positioning System. But attention to the engineering and operational challenges involved in protecting those capabilities from both man-made and environmental interference has not kept pace. The recent Chinese antisatellite test highlighted the vulnerability of space assets, but success in protecting space capabilities will face several lesser known and very difficult challenges that are unique to the space domain.

The first challenge for space protection is that spacecraft must operate in the hostile radiation and debris environment of outer space, often for decades without any easy or practical (that is, inexpensive) means for repair or replacement. Design efforts aim to extend the design life and improve operational performance of spacecraft, but more can be done. The second challenge is to improve the operational techniques for space systems. Spacecraft often provide extremely limited data from which to infer what is happening in orbit. Available data must be aggregated, technically analyzed, and interpreted in order to develop courses of action. The third challenge is that lengthy spacecraft development cycles may delay the introduction of needed changes for five or 10 years or longer, and a change to the entire architecture of space capabilities would take even longer than that. Finally, a robust strategy to protect space capabilities would allow the rapid re-establishment of any lost capability either through replenishment of lost systems, or augmentation with terrestrial or airborne capabilities where feasible. Addressing each of these challenges will require good forward planning and execution from the myriad organizations involved in space system development, both commercial and military.

The Challenge of the Space Environment

The space environment presents some unique hazards that can disable a spacecraft quickly and permanently. These include man-made debris moving at orbital speeds, and the extreme natural radiation environment of space.

From a daily operations perspective, the man-made debris hazard in space is a source of significant concern. Currently, for example, tens of thousands of objects, mostly debris, are being tracked in orbit. Any object in orbit moves at very high speed (e.g., 18,000 mph), and for this reason its orbit is not easily changed. As a result, the location of space assets is relatively easy to predict but difficult to change. Space debris is also moving at high speed and will persist in orbit for many years, sometimes indefinitely. Collisions between assets and debris moving at these speeds can be catastrophic and very difficult to avoid. Debris the size of a bolt, for example, can inflict significant damage. Therefore, concerted effort in the international community to identify existing debris hazards, develop strategies to avoid damage, and limit creation of new debris will be a necessary and permanent feature of future operations. The problem of tracking tens of thousands of objects with the necessary precision is technologically challenging, and improved methods of tracking and planning must be developed. The Department of Defense (DoD), The Aerospace Corporation, National Aeronautics and Space Administration, and others have been active in developing such methods for many years, but more remains to be done.

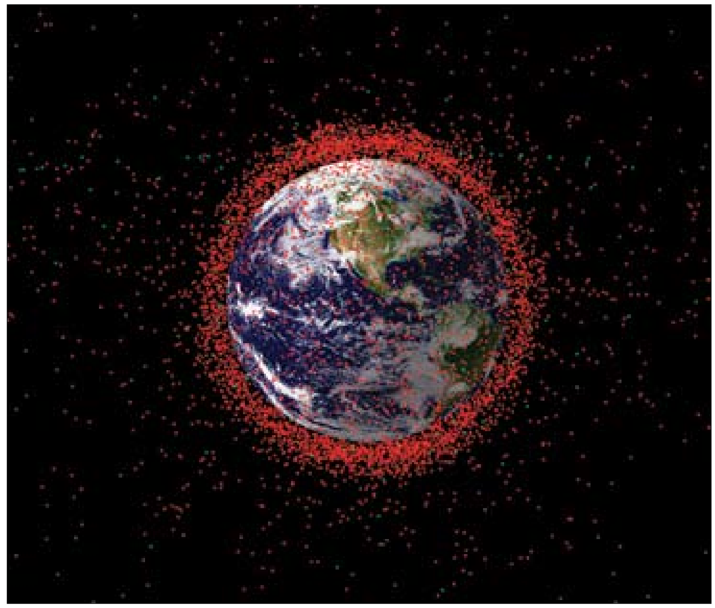


Figure 1. Computer-generated representation of man-made debris in orbit around Earth.

Another important problem in protecting space assets arises from the extreme natural radiation environment in space. This radiation can affect electronic components in ways that mimic ordinary malfunctions, making it very difficult to identify whether the problem is the result of "space weather" or of hardware failures. Improved monitoring of the space environment, more radiation-tolerant components and designs, and better onboard monitoring would all contribute to improved protection by providing better information upon which to base operations

decisions. Methods to help detect the difference between radiation-induced failures and equipment failures have been deployed to ground stations in the past, but much more can be done to improve awareness of the effects of the environment on spacecraft and electronics, and to assist operators in correctly diagnosing problems and developing solutions.

The Challenge of Improving Operational Techniques

Satellites contain sensitive electronics, optics, and fine mechanical structures that must operate 24 hours per day for many years without any easy means for their repair or replacement. Virtually all space systems are operated by remote control from the ground, so determining the exact cause of a problem on an orbiting spacecraft must be done by inference using the very limited data coming from the on-board spacecraft telemetry. Although the available "health and status" information coming from spacecraft has increased, current spacecraft and their ground systems are not designed to help detect and diagnose many problems that can occur in orbit.

An example of this difficulty can be seen in the problem of radio frequency interference with spacecraft. Many nations utilize the congested radio frequency spectrum available to space systems, and there is a potential for both intentional and unintentional interruption of space services through radio frequency interference. The interfering signal may originate from nearly any point on the visible portion of Earth and therefore be difficult to locate. Quickly determining the problem and locating the source of the interference on the ground is challenging, and requires effective operational procedures and analysis. New systems will be necessary, such as the Rapid Attack Identification Detection Reporting System being fielded by the Air Force.

In 2006, 14th Air Force Commander, Lt Gen William L. Shelton, reported that Panamsat, and other commercial and international satellite communication systems, had been intentionally jammed, indicating a clear need to quickly locate the source of the trouble and bring appropriate pressure to bear to resolve the problem. Interference with these assets may not only result in substantial commercial losses, but may also affect military operations due to the use of commercial services by the military. Unintentional interference can often be resolved privately if the source can be identified, but intentional jamming may require governmental intervention. As in many areas of the space domain, international cooperation would provide additional sources of information concerning problems, and also lead to quicker and more effective solutions.

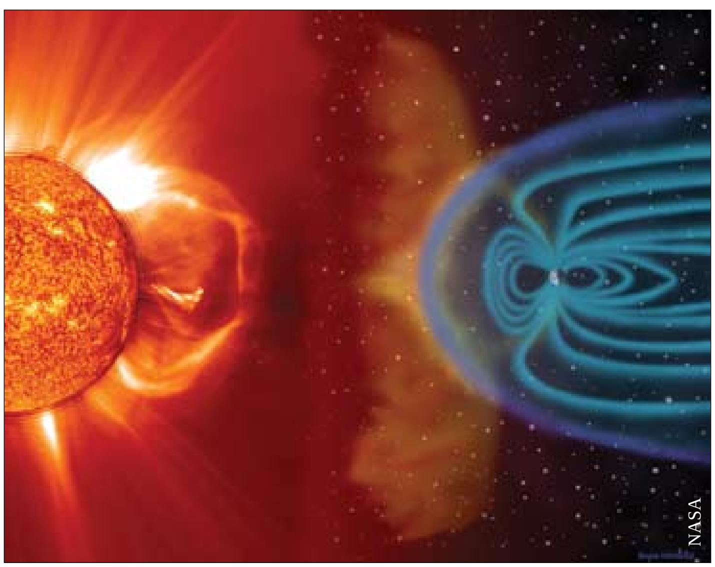


Figure 2. Representation of solar wind-generated radiation environment that can impact space asset effectiveness.

The data available to decision-makers regarding events unfolding in space is often imprecise and untimely, yet actionable options must be developed quickly. Therefore, it will be necessary to rapidly detect service disruptions, attribute the source of the problem in order to assess the impact, and to reconstitute the space capability quickly if necessary. But good decision-making is dependent upon good information, and it will be necessary to create and maintain a more comprehensive picture of the state of the situation in space in order to operate more effectively. Clearly, much more sophisticated monitoring of spacecraft, as well as the development of methods for improving the onboard sensing (detection, analysis, recording, tracking) of electromagnetic and laser energy that could be potentially damaging to satellite systems, would help promote effective action.

The Challenge of Lengthy Development Cycles for Space Systems and Architectures

The long development and life cycles for many spacecraft, particularly the more complex national security satellites, demand a strategic approach to develop and implement protective measures. Space systems may require ten years to design, develop, and deploy in orbit, and needed changes may not be introduced into service for years. Once launched, most current space systems cannot be modified substantially to respond to new challenges, and early replacement would be extremely expensive. Therefore it would be prudent to implement a twofold strategy that includes making spacecraft more adaptable once launched, coupled with a capability to "operate through" disruptions until an effective solution can be implemented.

An example of an area in which spacecraft might be made more adaptable is in the mitigation of radio frequency interference on satellite operations. The Aerospace Corporation and others have developed techniques to adaptively mitigate such interference to allow continued operations, but such techniques are not routinely used due to added expense and complexity of such design. A second example can be seen in systems such as the Transformational Satellite program and other spacecraft, which will likely have communication systems more in common with the internet than current systems do. This will necessitate information assurance measures similar to those that now protect against viruses in desktop computers, and intrusion into databases. Software and other onboard systems will have to be adaptable to mitigate problems that may arise over time in this area. More adaptable spacecraft may be able to "operate through" problems more effectively, but a more robust strategy would require designing and deploying flexible architectures (collections) of space assets and possibly other assets as described next.

The Challenge of Reconstituting or Augmenting Space Capabilities

Regardless of how adaptable and robust any individual space asset is, we will need to consider the flexible use of the entire portfolio of space assets and capabilities in order to compensate for the loss, whether permanent or temporary, of any space asset. Both military and commercial space system operators have used this strategy in the past to compensate for the loss of an asset by replacing it with another orbiting asset that was underutilized. However, this can only be done in specific, rather limited circumstances, such as in geosynchronous orbit where spacecraft can be shifted at relatively low expense. With careful planning and investment, however, the number of opportunities to provide backup capabilities could be increased, and the time needed to make adjustments for nonfunctioning assets could be shortened. In fact, this concept could be generalized to include augmentation by terrestrial and airborne capabilities in some circumstances.

However, there are important technical and economic difficulties that have limited progress in this area. For example, the cost of early replacement of existing space assets is usually prohibitive, often in the hundreds of millions of dollars, and the time required for launch is not responsive, often requiring many years. This had led to calls for more responsive systems such as the DoD's Operationally Responsive Space Program, which typically considers smaller, lower-cost satellites that can be fielded quickly. This approach can provide numerous possibilities for innovative concepts, including concepts for constellations of small satellites that operate together. Such constellations hold the promise of being robust due to their distributed nature, and the possibility that they might degrade more gracefully than other architectures. At present, small satellites cannot replace the capabilities provided by larger satellites, but in the future, innovative architectures of this kind may one day augment capabilities and improve protection. Similarly, augmenting space capabilities with airborne or terrestrial capabilities may be equally difficult because space systems provide unique capabilities with respect to Earth coverage, timeliness, and other characteristics. Nonetheless, airborne and terrestrial capabilities could augment or temporarily replace space capabilities in certain circumstances, such as in the use of unmanned aerial vehicles to relay communications. In any case, implementing "architecture solutions" to help protect space capabilities will require a long-term commitment and coordinated actions among the various agencies that currently plan and procure these systems.

Conclusion

Recognizing that our reliance on space capabilities is growing and that our investments are large would suggest that an ounce of protection is worth ten pounds of cure. We are fortunate that intentional interference with space systems has so far been extremely rare. But increasing worldwide recognition of the US dependence upon space capability now, more than ever, demands greater vigilance and improved protective measures. Therefore a multifaceted approach to improving the security of space capabilities is needed, including improved surveillance, improved protection of space and ground assets, more robust architectures, and better operational procedures. Doing all these things will require a long-term strategy with effective means of coordinating government actions, and to the extent possible, the actions of commercial space operators.

Clearly, technical solutions are only part of what must be addressed by a national space protection strategy; there must also be international and diplomatic actions aimed at ensuring freedom of access to and use of space for all. Thus, protecting our space capabilities has been and will continue to be an engineering, operational, and diplomatic challenge.

A number of hopeful steps have been taken in this direction, the most recent and important one being the establishment of the Space Protection Program, which is a joint program of the Air Force and the National Reconnaissance Office that will provide recommendations on how to best protect our space assets. The memorandum establishing this program on 31 March 2008, states that the program will assess vulnerabilities and provide strategies and roadmaps for improving protection of space capabilities. As we have seen, the scope and technical difficulty of developing and implementing such strategies will be large. However, the impact of losing these vital national assets would be immense, and we must take prudent steps now to improve the protection and security of space capabilities.

Dr. Wanda M. Austin (BS, Mathematics, Franklin & Marshall College; MS, Systems Engineering and Mathematics, University of Pittsburgh; PhD, Systems Engineering, University of Southern California) is the president and chief executive officer (CEO) of The Aerospace Corporation, an independent, nonprofit organization dedicated to the objective application of science and technology toward the solution of critical issues affecting the nation's space program.

At Aerospace, Dr. Austin has been the general manager of the Military Satellite Communications Division, where she was responsible for systems engineering support to the Air Force in the architecture, acquisition, development, and orbital operation of advanced satellite communications systems and programs. She was senior vice president of the Engineering and Technology Group, directing a staff of 1,000 engineers and scientists working in a wide range of space-related disciplines. Before being named president and CEO, Dr. Austin was senior vice president of the company's National Systems Group, which supports the national-security space and intelligence community in the acquisition, launch, and orbital operation of advanced technology space systems and their ground data stations.

Dr. Austin is internationally recognized for her work in satellite and payload system acquisition, systems engineering and system simulation. Among her many awards are the Air Force Scroll of Achievement, the National Reconnaissance Office Gold Medal, NASA's Exceptional Public Service Medal, and the Air Force Meritorious Civilian Service Medal. She is a member of the National Academy of Engineering.

Promoting the Safe and Responsible Use of Space: Toward a 21st Century Transparency Framework

Maj Patrick A. Brown, USAF
Space Protection Program (Integration)
Headquarters Air Force Space Command/National Reconnaissance Office
Peterson AFB, Colorado

Since the dawn of the Space Age, the United States has consistently expressed its commitment to the basic principles first advanced by the US, and its support for the Outer Space Treaty and other elements of international law. The most fundamental principle is the safe and responsible use of space. With public and congressional opinion keenly focused on the need to protect US economic and national security space interests, and the need to preclude any misunderstanding of intentions in space, this article proposes a conception of ways and means that approaches space protection through increased transparency with the objective to promote global prosperity.

The current environment of relatively stable relations between space-faring nations allows for the international community to evolve, increase and delineate transparency efforts before sterner tests of resolve, patience and commitment can occur. As a leading proponent of international cooperation to ensure safe and responsible use of space through measures such as mitigation of orbital debris and collision avoidance warning, there is significant value of increased voluntary transparency measures. A renewed effort toward a transparency framework consistent with US National Space Policy and enabling international cooperation has the potential to enhance satellite safety and reduce uncertainty in an evolving space security environment. Shared knowledge through space situational awareness will be the key factor for this effort.

Recognizing the Benefits of Space to World-wide Prosperity

The international community already recognizes and exploits the benefits of space for world-wide prosperity, so it may seem capricious here to restate the contributions of space to human endeavors, but nonetheless, the contributions of space services to commerce; weather; precision, navigation, and timing (PNT); search and rescue; television; and earth sensing are clear manifestations of our reliance on space services to maintain a quality of life and accustomed prosperity.

For example, as of 15 August 2008, the National Oceanic and Atmospheric Administration's (NOAA) reports 191 COSPAS-SARSAT rescues in the US for 2008. Worldwide, this system has rescued over 24,500 people since 1982. With a combination of low-Earth orbit and geosynchronous satellites from the US, the European Union (EU), Russia, and India, the international COSPAS-SARSAT program continues to grow and be a model of international cooperation. According to NOAA, "the four original member nations have now been joined by 29 other nations that operate 45 ground stations and 23 mission control centers worldwide or serve as search and rescue centers."[1]

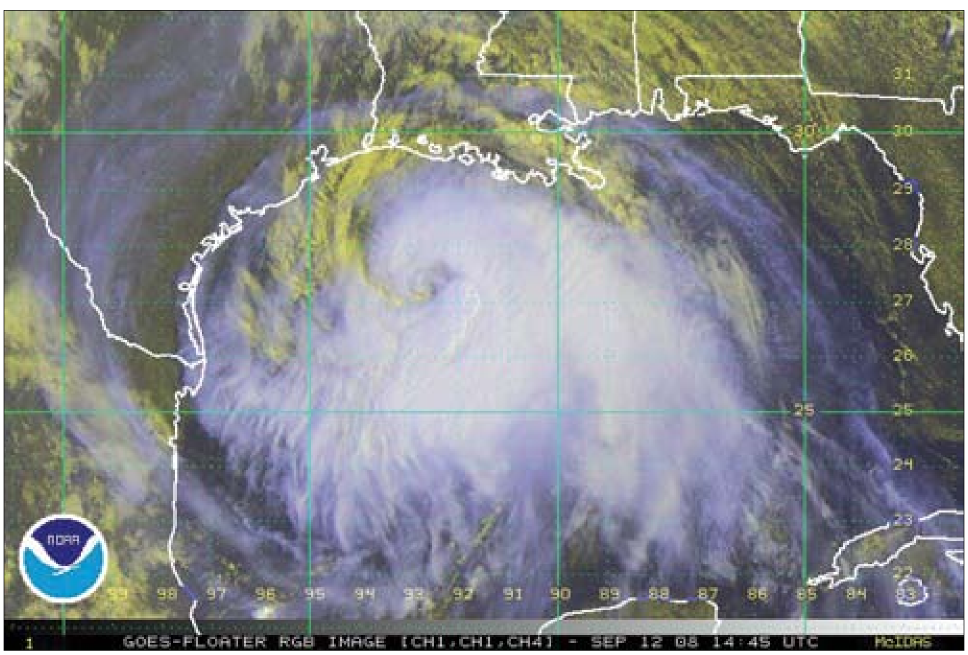


Figure 1. National Oceanic and Atmospheric Administration Satellite and Information Service - Geostationary Satellite Server.

Further, at the time of this writing, Hurricane Ike is bearing down on the Texas coast. Unlike the Galveston storm of 1900 that claimed over 6,000 lives, an Atlantic basin hurricane in 2008 is monitored by weather satellites from its conception on the west coast of Africa allowing early modeling and preparation. Hurricane hunters are tracked with Global Positioning System (GPS)-equipped Iridium-based blue force trackers while surveying the storm; search and rescue helicopters and emergency management personnel with the same trackers and mobile satellite communications are poised to render aid to those who did not evacuate following landfall. Many news commentators noted that the orderly evacuation from the Texas coastal areas including Galveston was attributable to the vast amount of data available to citizens and civil personnel—sadly, many citizens will choose to ride out the storm. The

One could envision an international space community embracing earthly "green" practices to make space "environmentally friendly" and find methods and capabilities to "recycle" space debris.

same could be said for cyclones and massive flooding in Myanmar, Burma or earthquake recovery operations in China. So, as more country's become space-faring nations or come to rely on space services, the international community will look to those same countries to act as responsible stakeholders that cooperate with other nations to advance the common interests of all humanity in outer space.

Cooperation with other nations in all aspects of space could contribute to the development of mutual understanding and strengthen the relationship between governments. In this regard, the principles of transparency, reciprocity, and mutual benefit must serve as the guiding principles for any bilateral or multinational cooperation.

Protection through Increased and Sustained Transparency

All nations must now know the imperative to protect space interests. As stated above, protection can be achieved through transparency measures. In doing so, however, applying a common understanding of transparency—a framework—is elusive. In a multinational arena, long understood or evolving cultural trends weigh heavily on the interpretation and decision process. One countries interpretation of transparency, or even literal translation, is often divergent from another's. Therefore, a common framework with globally acceptable measures must follow.

To further illuminate the difficulty of understanding transparency, I offer several non-conclusive attempts at a definition. Transparency could be an approach which results in building confidence through predicable and repeatable behavior. Transparency can also take the form of clear, declaratory policy statements. Or, it could also take the form of open architectures or shared data sources, when possible. In all forms, the central goal of the transparent measure is to reduce uncertainty over intentions. In the following, I sight two examples of US transparency from this last year relative to space activities designed I believe to communicate intention and reduce uncertainty. The first is the state of GPS and the second is the USA 193 engagement.

For the undetermined future, the US will continue to provide civil and military PNT signals by GPS. Even as the US, Japan, China, Russia, and the EU develop and field improved regional PNT services and space-based augmentation systems like the Federal Aviation Administration's Wide Area Augmentation System and Japan's Multi-functional Satellite Augmentation System, the global community still requires GPS. A small set of examples include international shipping, civil search and rescue, and timing for international banking transactions. Other countries have come to rely on GPS and can ill afford to build their own. The US is committed, and frankly now has the obligation, to continue this service for the benefit of all. As a testament to this, the next generation of GPS satellites will no longer continue the selective availability option and additional civil signals are being offered on the latest and next generation satellites.[2]

The US also demonstrated the use of transparency before and after the USA 193 engagement. The US notified the United Nations, foreign governments, and the broader international community well prior to the event. Presentations were made discussing the anticipated results of the engagement and noted that the action was consistent with all US national and international orbital debris mitigation guidelines. Following the successful engagement, modeling data and debris totals demonstrated projected deorbit times. The USA 193 engagement represents the value of US transparency in the quest to protect the public from a potentially harmful reentry while protecting shared interests in the global commons of space and Earth.

In fact, over the years, space users have literally littered space with rocket bodies, debris, and errant satellites, purposefully and negligently, easily accepting this as the cost of doing business in the unforgiving environment of space. Currently, the Joint Space Operations Center at Vandenberg AFB, California tracks "more than 18,000 man-made objects in space, to include everything from active satellites to man-made debris."[3] One could envision an international space community embracing earthly "green" practices to make space "environmentally friendly" and find methods and capabilities to "recycle" space debris. Examples of this may include deorbiting errant objects in low-Earth orbit, or exploring ways to remove dead objects in the geosynchronous belt.

This responsibility is not the US's alone. Every space-faring nation, international consortia, and commercial space provider has the responsibility and right to protect its space interests—economic, investments, and national security. In this manner, all cooperative countries should provide for mutual protection at every opportunity. Not only are these goals consistent with US National Defense Strategy and US National Space Policy, but also with international norms and conventions.

Finally, returning to the previous statement on open architectures or shared data sources, a potentially definitive transparency measure for space protection is shared knowledge. The best source of shared knowledge given the lack of clear, declaratory policies or stated and followed intentions, is derived from shared space situational awareness (SSA).

Shared Space Situational Awareness

Past proposals for international confidence building space activities include more stringent debris mitigation, collision, and explosion avoidance measures, the development of safer traffic management practices, improved information exchanges,

and notification measures related to space safety. In this regard, SSA is foundational. SSA is "the requisite current and predictive knowledge of the space environment upon which space operations depend—including physical, virtual, and human domains—as well as factors, activities, and events of friendly and adversary space forces across the spectrum of conflict."[4] Simply, shared SSA is the ability to discern the true nature of an event in space and take positive, full spectrum actions from notification, maneuver, and demarche to last resort military action to prevent a disruption to space services. The Department of Defense's June 2008 *National Defense Strategy* tempers this best:

> The best way to achieve security is to prevent war when possible and to encourage peaceful change within the international system. Our strategy emphasizes building the capacities of a broad spectrum of partners as the basis for long-term security. We must also seek to strengthen the resiliency of the international system to deal with conflict when it occurs. We must be prepared to deal with sudden disruptions, to help prevent them from escalating or endangering international security, and to find ways to bring them swiftly to a conclusion.[5]

For the US, SSA enables command and control of space resources to ensure timely and accurate decision making for both military and non-military space operators and users. It enables decision makers the ability to fully leverage and protect American and allied space capabilities. SSA is developed by integrating, fusing, exploiting, analyzing, and displaying traditional and non-traditional space surveillance, reconnaissance, intelligence, and environmental sensor information and data sources along with system health and status information provided by space system operators.[6] Finally, SSA promotes open communications and understanding providing a mechanism for escalation control and exclusion of misunderstandings.

The challenges and opportunities of shared SSA can be illustrated by the pilot program, Commercial and Foreign Entities (CFE). Approved by the Office of the Secretary of Defense in October 2004, CFE provides two-line element sets, decay predications, launch support conjunction assessment and reentry support and anomaly resolution to qualified customers. However, balancing national security requirements of the US, allies and friends against the desire for transparency has resulted in less than complete information sharing. A renewed effort toward CFE would continue to function as a baseline to greater cooperation and collaboration on space surveillance data.

The US should seek out and engage in mutually beneficial space partnerships and space engagement activities in order to promote sustainable space safety. Collaborative programs with allies, friends, and other states will be used to promote continuity of service, interoperability, and development of collaborative space systems, including grounds segments, when possible. These are important ways to share the cost of space capabilities, lower tensions, promote economic development through the use of commercial space activities and foster transparency. These actions will increase the use and value of space for the international community and assist in achieving key US assurance, dissuasion, and deterrence objectives.

And with multinational cooperation to SSA, the value of shared SSA will increase exponentially. All space users have a vested interest in space, and unlike any other domain, we must continue to educate them on the cataclysmic effects of irresponsible use of space. Unlike a massive oil spill along a coastal plain or effects of irresponsible manufacturing plant runoff into rivers that Mother Nature can correct over time, effects in space are mostly permanent. In fact, a collision or massive explosion of large satellites at geosynchronous orbit has the potential to "pollute" the belt with debris for certainly our lifetime or longer without human intervention to "reclaim" the use of space orbits.

Shared SSA, consistent with the earlier attempts of defining transparency, will increase predictability in space, allow for timely maneuvering decisions on fuel and longevity concerns, and reduce uncertainty and misunderstanding for any purposeful interference conditions should they occur, and they will. Shared SSA, if successful as a transparency and confidence building measure, also reinforces other sharing efforts in Earth and space science, human space flight and space exploration. Again, the value and benefits are exponential.

Setting the Tone for Future Cooperation

Bilateral engagements such as those conducted earlier this year between NASA and Chinese scientists, the US Air Force Academy's Eisenhower Center sponsored informal discussions with Chinese officials in Vancouver, Canada, and previous military officer visit exchanges, all support the concept of setting the tone for future cooperation related to space. Identification of new opportunities for expanded cooperation with space-faring nations should begin now. Protection through transparency is critical to reversing possible trends in an evolving space security environment.

The international community should accelerate engagement activities now to increase and sustain transparency efforts. This investment of time and funds to support engagement will prove invaluable over time and is essential to strengthening relationships prior to any adverse changes in the current the geopolitical environment. The international community must be prepared for rogue nations or irrational actors to conduct actions in or through space contrary to the purpose of this article. Acceleration of efforts toward these ends now while the space environment is relatively stable and resources are primed, ensure a sustained focus envisaged to reap mutual benefits and preserve the peaceful use of the space domain for the global commons.

Historically, the US has rested on the assumption of the US as an "indispensable nation."[7] The National Defense Strat-

All space users have a vested interest in space, and unlike any other domain, we must continue to educate them on the cataclysmic effects of irresponsible use of space.

egy on some level supports this comment: "The security of the United States is tightly bound up with the security of the broader international system."[8] With respect to space, despite the abundance of US capability to provide situational awareness, the proliferation of space assets and services, the global dependence on those services, and the ever increasing pressures to promote ideals without an overt use of power, soft or hard, will encourage the international community to readjust to a new reality of increased and sustained transparency geared toward promoting global prosperity. The National Defense Strategy goes on to say, "… our strategy seeks to build the capacity of fragile or vulnerable partners to withstand internal threats and external aggression while improving the capacity of the international system itself to withstand the challenge posed by rogue states and would-be hegemons."[9]

Charting a Way Forward

In last quarter's *High Frontier*, I stated, "The US must apply innovative thinking to exploit the inherent advantages of the space medium and enhance space capabilities to help solve the security challenges we are faced with today and in the future."[10] I repeat that call in this article for the US and the larger international community to promote and act on initiatives for voluntary transparency measures. Again the National Defense Strategy provides the enabling language: "Both China and Russia are important partners for the future and we seek to build collaborative and cooperative relationships with them. We will develop strategies across agencies, and internationally, to provide incentives for constructive behavior while also dissuading them from destabilizing actions."[11] The National Defense Strategy strikes the right balance between building collaborative and cooperative relationships with the international community and protecting US interests through all-encompassing strategies using all elements of national power not just the obvious military power.

To that end, the US can move out with full funding of CFE or a similar program to provide shared SSA under the current legal regimes while the current environment and relations are relatively stable. Release and openness of the data consistent with national security of the many participants should not hinder the mutual benefits of this program. Further, the US should engage in bilateral and multilateral engagements to build confidence and establish with the international community improved, voluntary measures on more stringent debris mitigation, collision, and explosion avoidance measures, the development of safer traffic management practices, improved information exchanges and notification measures related to space safety. This approach to space protection through increased transparency, while not new, if acted on now can lead to improved collaboration and cooperation consistent with US national policy and defense strategies.

The author wishes to acknowledge the following for contributing to the article: Dr. Andrew Palowitch (director, Space Protection Program), Col Joe Squatrito (deputy director Space Protection Program), and Mr. Martin Oetting and Ms. Elizabeth Woish (The Aerospace Corporation).

Notes:

[1] NOAA SARSAT, http://www.sarsat.noaa.gov/, accessed 12 September 2008.

[2] Michael Shaw, director, US National Coordination Office for Space-Based Positioning, Navigation, and Timing (PNT), "US Space-Based Positioning, Navigation and Timing Policy and Program Update," 4 December 2007, http://pnt.gov/public/2007/2007-12-IGNSS/shaw.ppt, accessed 12 September 2008.

[3] Louis Arana-Barradas, "The Space Link," *Airmen Magazine*, July/August 2008, 12.

[4] DoD, *Space Situational Awareness Strategy and Roadmap Report to Congress*, 16 April 2007.

[5] Robert M. Gates, US Secretary of Defense, National Defense Strategy, http://www.airmanonline.af.mil/shared/media/document/AFD-080630-074.pdf, June 2008, p. 9..

[6] HQ Air Force Space Command (AFSPC), *National SSA Roadmap*, April 2008.

[7] Robert Kagan, *Of Paradise and Power: America and Europe in the New World Order* (New York, 2003) 94.

[8] Gates, Ibid., 6.

[9] Gates, Ibid., 6.

[10] Patrick A. Brown, "Rescuing Apollo: Building Consensus toward a National Strategy for Space," HQ AFSPC, *High Frontier* 4, no. 4 (August 2008) 38.

[11] Gates, Ibid., 11.

Maj Patrick A. Brown (BBA Management, Midwestern State University; MS, Administration, Central Michigan University; MMOAS) is assigned to the Space Protection Program (Integration), Headquarters Air Force Space Command (HQ AFSPC)/National Reconnaissance Office (NRO), Peterson AFB, Colorado. He is responsible for providing the Space Protection Program director with a comprehensive range of options and recommendations for integration of operations and intelligence protection capabilities and effects. He maintains current knowledge of intelligence and national defense needs and anticipates future space protection needs, and maintains a close two-way collaboration between AFSPC and NRO operations and intelligence functions. Major Brown was commissioned from Air Force Officer Training School in 1993. His career includes assignments as a missile combat crew commander at Minot AFB, North Dakota, a missile combat crew initial qualifications instructor and training flight commander at Vandenberg AFB, California, the sole space advisor, planner, and chief of Special Technical Operations (STO) for 9th Air Force/US Central Command Air Forces commander at Shaw AFB, South Carolina, the assistant director of operations for the USAF Weapons School's space squadron at Nellis AFB, Nevada, and HQ AFSPC staff positions as a command lead and Strategic Studies branch chief. He has deployed numerous times to theater combined air and space operations centers to include positions in strategy and STO during Operation Iraqi Freedom's Major Combat Operations from February to April 2003, the primary Afghanistan air strategy planner for Operation Enduring Freedom from December 2003 to March 2004, and other deployments where he performed duties as lead space weapons officer, space strategist, STO chief, and deputy director of space forces in support of major theater exercises. Major Brown is a resident graduate of the Squadron Officer School, Air Force Weapons School, and Air Command and Staff College.

Components of a Space Assurance Strategy

Mr. Samuel Black
Research Associate
The Henry L. Stimson Center
Washington, DC

A space assurance strategy strives to ensure that the president, US armed forces, and US citizens, allies, and friends can call upon space assets when needed. This is easier said than done because satellites are as valuable as they are vulnerable. A carefully-considered space assurance strategy requires three component parts in proper measure and priority: effective diplomacy, defensive measures to make satellites harder to attack, and latent antisatellite weapon (ASAT) capabilities. Diplomacy can establish norms that are in the net national security interests of the US because they clarify responsible behavior and facilitate responses to irresponsible behavior. Defensive measures can be useful at the margin, but are likely to provide only limited physical protection. However, they can bolster deterrence by making it more difficult for disruptive attacks to succeed and by making severe penalties for such attacks more likely to succeed. Great care must be exercised with regard to offensive hedges. The deployment and use of latent ASAT capabilities can pose grave hazards because they can result in making the use of satellites less assured. Most US presidents have considered the use of ASATs as a last resort under exceptional circumstances and have been inclined to support diplomatic initiatives that strengthen norms promoting the peaceful uses of outer space. In recent years, increased efforts have been focused on defensive measures that make attacks on satellites less likely to disrupt the vital services that they provide.

I argue that space assurance is most likely to be achieved by relying on defensive countermeasures and diplomatic initiatives that strengthen international norms against harmful interference with satellites. I further argue that the deployment and first use of ASATs by the US are most likely to decrease space assurance by undermining norms for the peaceful uses of outer space and by prompting asymmetric responses from potential adversaries. Dedicated ASATs are unnecessary because the US has other means to respond forcefully to punish those who would be foolish enough to attack US satellites, including by means of existing systems with the latent capability to attack satellites. To further dissuade other space-faring nations from deploying and using ASATs, I endorse the continued research and development of multi-purpose technologies that clarify US capabilities to respond to threats against satellites.

The Three Components

Beginning with Dwight D. Eisenhower, US presidents have pursued diplomatic initiatives, including tacit and explicit agreements, to establish common restraints protective of satellites. The most successful of these form the cornerstones of the international legal regime which facilitates the peaceful use of outer space. The Limited Test Ban Treaty prohibits nuclear explosions in outer space, and the Outer Space Treaty bans the placement of weapons of mass destruction in orbit.[1] The latter also states that nations cannot claim parts of outer space or celestial bodies as their sovereign territory, and calls for all nations to use space for peaceful purposes. Other agreements, including SALT I (Strategic Arms Limitation Treaty Agreement), the Intermediate Range Nuclear Forces Treaty, and the Threshold Test Ban Treaty, include provisions against harmful interference with the satellites used to monitor compliance with their provisions.[2]

Presidents have been cognizant of the limitations of diplomacy, and have not been willing to rely solely on diplomacy to provide for space assurance. They have also endorsed defensive measures that would make such attacks less likely to disrupt satellite operations. Defensive measures for space assurance include physical protections against some forms of attack. Increasing redundancy and satellite maneuverability, hardening satellites against jamming and lasing, and improving space situational awareness (SSA) are all ways of reducing satellites' vulnerability to attack.

Offensive measures are a third possible way of addressing the satellite vulnerability problem, but are by far the most problematic. These efforts sharpen conflicts with major space powers and distance the US from its allies and friends. They are also likely to accelerate offensive hedges by key space-faring nations, reducing space assurance. Consequently, US presidents have usually viewed the use of ASATs only in the event that attacks on satellites cannot be avoided. US presidents have been able to authorize the use of weapons systems that were not expressly designed to destroy satellites, but that have the capability to do so. For example, the Aegis Ballistic Missile Defense system was used in February 2008 to destroy a satellite, though this is not its primary function.

Space Diplomacy

The administration of President Dwight D. Eisenhower concluded at the dawn of the space age that US national security interests would best be served by accepting—and indeed, exploiting—satellite operations, even at the risk of allowing unimpeded Soviet satellite operations. The Eisenhower administration promoted the concept of "freedom of space" as early as 1955, and adopted the principle that all nations had the right to use space for "peaceful" purposes.[3] However, the National Security Council urged that care be taken "not to prejudice US freedom of action … to continue with its military satellite programs."[4] This interpretation of "peaceful," one that accepts the use of space for some military functions, has subsequently been widely accepted. The USSR initially objected to this interpretation, but dropped in October 1963 its position that satellites and aircraft should be treated equivalently (and that therefore satellite overflights were illegal).

Eisenhower's diplomacy had mixed results. Some of his initiatives, like a push to establish an international body to inspect all rocket payloads, failed completely. Others, like the creation of the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS), required sustained support to get off the ground. COPUOS was established in December 1958 but failed to meet for three years due to a Soviet boycott.[5]

In July 1962, Secretary of State Dean Rusk told President John F. Kennedy that "the US probably cannot keep the Soviets from attempting physical ASAT measures if they decide to do so."[6] The Kennedy administration decided that the US should conduct diplomacy while also hedging its bets. In a major breakthrough, Kennedy negotiated the Limited Test Ban Treaty, which banned any nuclear tests in outer space.[7] This treaty set a limited norm protecting satellites against the damaging effects of nuclear explosions, though both sides retained the means to violate this norm. The Kennedy administration also led discussions on banning the placement of weapons of mass destruction in space that led in 1963 to the passage of a resolution by the United Nations General Assembly, "Stationing Weapons of Mass Destruction in Outer Space." This resolution endorsed statements made by the United States and Soviet Union in which both stated their intentions not to place weapons of mass destruction in orbit.[8]

Under President Lyndon B. Johnson, the US built on the foundation laid by the General Assembly resolution. Negotiators concluded an agreement which set the basic parameters binding space operations, the Outer Space Treaty of 1967. Parties to the treaty have pledged to use space "for the benefit and in the interests of all countries" and "in the interest of maintaining international peace and security."[9] The treaty limits all sovereign claims and some military activities in space. The Outer Space Treaty also laid the groundwork for later treaties, including the Moon Treaty, Registration Convention, and Liability Convention. President Richard M. Nixon built upon this foundation and oversaw the negotiation of several arms control agreements which established the principle that certain types of satellites were deserving of protected status to help monitor compliance with arms control obligations.

Presidents Gerald R. Ford and Jimmy E. Carter both supported the pursuit of hedging strategies to support diplomatic initiatives. Two days before the end of his term, Ford approved a new US policy on ASAT capabilities. It directed the secretary of defense to acquire a non-nuclear ASAT while simultaneously urging the consideration of diplomatic initiatives that would "raise the crisis threshold for use of an antisatellite" and restrict the development of high-altitude ASATs.[10] President Carter continued this approach. In Presidential Directive/NSC-33 he authorized an ASAT testing schedule for the explicit purpose of using the tests as leverage in negotiations with the Soviets.[11] This leverage was insufficient to produce a deal before the Soviet invasion of Afghanistan brought an end to negotiations on strategic arms reductions and ASATs.

The tradition of favoring diplomacy was briefly interrupted during the first term of President Ronald W. Reagan. While his 1982 National Space Policy did not rule out space arms control entirely, it was not closely linked to other military space programs and support for it was heavily qualified.[12] During Reagan's second term, he authorized the Nuclear and Space Talks, which failed to produce a substantive agreement on space issues, but which facilitated subsequent agreements securing deep cuts in deployed nuclear forces.

After the Cold War ended, President Bill Clinton saw no reason to pursue a treaty banning ASATs. Clinton's 1996 National Space Policy set "improving our ability to support military operations worldwide, monitor and respond to strategic military threats, and monitor arms control and non-proliferation agreements" as key priorities for US space activities. The policy also declared that "consistent with treaty obligations, the US will develop, operate, and maintain space control capabilities to ensure freedom of action in space."

The policy of President George W. Bush focuses primarily on ensuring US military freedom of action in space.[13] The Bush administration has been open to transparency and confidence-building measures, but only when they are voluntary in nature and do not curtail freedom of action. The administration has opposed space diplomacy when not in conformity with these parameters. At the same time, the Bush administration has not implemented key recommendations of the Rumsfeld Commission to Assess United States National Security Space Management and Organization, which called for, among other things, ensuring that "the president will have the option to deploy weapons in space."[14]

Diplomacy has established basic principles and norms that support the peaceful use and exploration of outer space. The Outer Space Treaty established the guiding principles of space activities. Subsequent treaties and multilateral agreements established transparency, safety, and liability measures which facilitate the use of space. Still other agreements have declared that states should refrain from taking certain actions that interfere with satellites. However, diplomacy has its limits. Many kinds of harmful interference are not specifically restricted by diplomatic agreements, and a number of countries maintain the capacity to break existing rules.

Defensive Measures

Purely defensive means for satellite protection are relatively uncontroversial and can reduce the vulnerabilities of space systems to some types of interference. Defensive measures generally fall into one of three categories: increasing the redundancies of space systems, protecting satellites against attacks at the margins, and improving SSA.

Some protective and defensive measures can only be justified on the grounds of cost effectiveness. Others may be required regardless of cost. For example, while only 24 satellites are absolutely necessary for the system to operate effectively, the US maintains a constellation of 33 Global Positioning System (GPS) satellites.[15] These nine additional satellites offer improved accuracy, and also make the potential loss of any one GPS satellite somewhat less costly in terms of the quality of the services provided by the system as a whole. Increasing the redundancies built in to other space systems, and particularly those with intelligence, surveillance, or reconnaissance functions, would be a useful step. It would reduce the degree to which harmful interference with satellites could exacerbate the destabilizing aspects of crises or armed conflicts. Protecting the developing norm against harmful interference is most crucial at such times.

Redundancy can also be approached in other ways. For example, the US can develop and maintain the capacity to accomplish missions currently performed from space with a mix of space-based and terrestrial systems. For some capabilities, like the precision navigation and timing provided by the GPS, this is not feasible. However, the suite of reconnaissance and communications systems can be diversified to include assets that are not based in outer space.

Work to protect satellites against various kinds of attacks is ongoing. Some measures, like enhancing satellite maneuverability,

can apply to almost any kind of satellite. Such efforts enhance the difficulties inherent to attacking fast-moving objects. Other efforts must be more focused. For example, the GPS is only useful to the extent that its signals can be received by individual receivers. As was discussed on these pages in May, GPS signals are quite weak.[16] Efforts to boost GPS signal strength are specific to this system, though the technology may be transferable to others. GPS-related defensive measures will have to keep pace with trends in technological development. The US has proven itself to be quite capable of doing so thus far.

To improve protection of other systems against interference the US must address different technical problems. Reconnaissance satellites, for example, can be "blinded," temporarily or permanently, by lasers. Efforts to protect against these technologies are currently under consideration, if not well underway.[17] By addressing some vulnerabilities of reconnaissance and other military support satellites, the attractiveness of these satellites as targets can be reduced. At a bare minimum, defensive efforts make it more difficult to disrupt satellite operations, and attempts to do so must be more forceful and thus less covert.

Enhancing SSA is also related to reducing the likelihood and effectiveness of attacks against US satellites. That the US must improve its SSA is accepted as fact by nearly all policymakers, practitioners, and commentators. If SSA is good enough, it can provide enough information about attacks to attribute them to an adversary, mitigate their effects, or avoid them altogether.

Any comprehensive space assurance strategy will need to include a growing defensive component. Many nations have gained access to technologies with the latent capability to attack satellites. These technologies can be used for other missions, and thus cannot reasonably be expected to be phased out simply because they threaten satellites. Furthermore, it may not be feasible or desirable to restrain with diplomacy all the ways of interfering with satellites. Defensive efforts can manage the threat posed by technologies that space-faring nations can not or do not want to ban.

Efforts to reduce the effectiveness of attacks on satellites have a number of advantages. By conveying a message to potential adversaries that attacks are less likely to succeed, satellite protections bolster deterrence. They mitigate, at least in part, the destabilizing effects of losing communications, early-warning, reconnaissance, or other space-based services during a crisis or war. Defensive measures are politically uncontroversial and thus do not interfere with diplomacy; they can support diplomacy by reducing the effectiveness of some types of interference. Many of these measures are cost-effective relative to the investments already made in satellites. The intersection of these advantages into a single option makes defensive counterspace efforts indispensable.

Offensive Hedges

All US presidents have pursued, to various extents, offensive hedging strategies to prepare for a worst-case scenario of space warfare. These hedging strategies have mostly been limited to the research and development of some multipurpose capabilities and the deployment of systems with latent ASAT capabilities. For a brief period of time after the Cuban Missile Crisis, the US deployed very limited ASAT capabilities. The first system, the Army's Nike Zeus, was quickly dismantled in favor of the second, the Air Force's Thor.[18] Both were acknowledged to be impractical because they relied on a 1.5 megaton nuclear warhead to destroy targets.[19] The US was well aware at that time that the use of nuclear weapons in orbit would result in the indiscriminate destruction of all satellites in the area.

The primary reasons for the reluctance of most previous US administrations to engage in dedicated ASAT testing have rested on national security grounds. Even those presidents who have had an interest in deploying dedicated ASATs have been stymied by the objections of Congress and resistance by allied countries, which help account for how few dedicated ASAT tests the US has undertaken. US ASAT tests would also likely trigger ASAT tests by other nations (and vice versa), thereby reducing space assurance for all space-faring nations.

The Soviet response to President Reagan's Strategic Defense Initiative (SDI) provides an example of how the rejection of diplomacy and the pursuit of space weapons and ASATs can be harmful to national security. Reagan's original budget plan for SDI called for $26 billion in spending over five years. While Congress appropriated half that amount, and no system was deployed, the program's existence prompted responses designed to defeat it.[20] Moreover, congressional majorities placed strict limits on ASAT and SDI tests, resulting in a severe disconnect between the Reagan administration's stated policy objectives and its ability to implement them. In effect, this disconnect resulted in severe disadvantages to the US, generating negative military and diplomatic responses while severely constraining the US military programs that prompted them. Thus, in ignoring diplomatic instruments that restrict US military freedom of action in space and investing heavily in space weapons, Reagan's policies led to a net increase of the threat facing US satellites.

The net consequences of the Bush administration's National Space Policy, which also denigrated diplomacy and emphasized US freedom of military action in space, were similar. Bilateral relations with potential adversaries and close allies deteriorated. Potential adversaries accelerated hedging strategies, as was evident in the series of Chinese ASAT tests, only the last of which was successful. This resulted in less space assurance. The asymmetric responses provoked by dedicated ASATs required more military spending to counter them. At a time when US national and economic security required more space assurance, the Bush administration's approach provided less space assurance.

A strike on US satellites would prompt the US to retaliate, and rightly so. However, there is no reason that this retaliation should be limited to others' satellites—most valuable targets are terrestrial and there is no reason to believe that reciprocal strikes against satellites would not be followed by a more general war. By definition, dedicated ASATs are useful for one purpose: attacking adversaries' satellites. If multipurpose systems like missile defenses can already accomplish this task and serve as a credible deterrent, there seems to be no need for dedicated ASAT programs, especially within the context of a space assurance strategy.

Offensive hedges, if not carefully configured, can be counterproductive. Tests and deployments of dedicated ASATs will surely trigger similar tests and deployments elsewhere. At the same time, there are no guarantees that restraint will be reciprocated. Therefore, the most prudent hedges are the latent capabilities which exist today.

The Way Forward

The diplomatic and defensive components of a space assurance strategy deserve greater emphasis. Physical protective measures that are cost-effective at the margin are clearly part of the solution to the dilemma of satellite vulnerability. Defensive measures include improving satellite maneuverability, hardening against lasing, better signal encryption, increasing redundancy, and performing missions with a mix of space-based and terrestrial platforms. Some satellite networks, like GPS, are so crucial that they warrant redundancy regardless of cost. Though the physical protection provided by defensive measures is limited, the message sent is clear. US satellites will be harder to attack, and if they are attacked, the US will retain the means to respond with deadly force. This is the essence of deterrence.

Diplomacy can build norms for responsible space-faring nations while clarifying irresponsible actions. Diplomatic agreements can seek to restrain the testing and use of dedicated ASAT weapons. The norm central to space assurance is not interfering with the normal operation of satellites. By establishing this and other norms, diplomacy establishes principles which enhance the legitimacy and effectiveness of responses to rule-breaking. Diplomacy can be backed up by the pursuit of hedges in the event of a failure of diplomacy, as was the case during the Carter administration, when Washington and Moscow tried unsuccessfully to negotiate a ban on space weapons. In the year from July 1977, the Soviets carried out five ASAT tests, while the US accelerated the Miniature Homing Vehicle program that eventually led to a successful air-launched ASAT test in 1985.[21] Funding for the program nearly tripled between Fiscal Years 1978 and 1981.[22] The two sides participated in three wide-ranging sets of talks between June 1978 and June 1979, though no agreement was reached.

When US administrations place a heavy emphasis on space warfare capabilities and denigrate diplomatic initiatives, the net effect is less, not more, space assurance. Presidents Reagan and George W. Bush adopted space policies that sought to maximize US military freedom of action in space while resisting diplomatic initiatives that restricted this freedom of action. The results in both cases were increased tension with other space-faring nations, increased US funding for systems with a dedicated or latent ASAT capability, and asymmetric responses and ASAT tests by potential adversaries. These policies made it more likely that an incidence of space warfare would be highly destructive. The number of threats to US satellites increased, while diplomacy was not used to strengthen norms against attacking satellites.

Future offensive measures must be confined to deployments of systems with latent ASAT capabilities and tests of multipurpose technologies. Latent capabilities, such as missile defense and lasers, will likely be developed and deployed in greater numbers. However, after the destruction of the USA-193 satellite in April 2008, no further tests on satellites are needed to clarify the latent ASAT capabilities of missile defense. Indeed, further tests of anti-ballistic missile systems in an ASAT mode would be seriously detrimental to space assurance in almost all circumstances. Multipurpose technology demonstrations should have clearly-defined goals which are oriented towards peaceful applications. Involving National Aeronautics and Space Administration would be one way of signaling these tests' benign intent. There are inherent tensions between diplomacy and hedging. Thus, clarity is required about diplomatic objectives and the downside risks of hedging strategies. Latent capabilities clarify US capabilities to respond in the event of a resumption of ASAT tests by others. There is no need to test and deploy dedicated ASATs to stress US capabilities.

Diplomacy is time-consuming and potentially unreliable—states have the option to break their word if they so choose. Diplomatic initiatives can also be disingenuous, serving as a cover for pursuing offensive capabilities. While recognizing these limitations, most US presidents have found significant value in setting norms conducive to space assurance. Norms cannot be set by military actions alone. Indeed, the absence of diplomatic norms makes resorting to force more likely and more difficult to succeed. If unacceptable behavior is not first clarified by diplomacy, isolating and punishing bad actors can be much more difficult.

The purpose of diplomacy is to clarify which actions are acceptable and which are not. Unacceptable actions must be verifiable. Diplomacy can also facilitate cooperation in other areas, such as space traffic management and debris mitigation. Diplomatic efforts have in the past yielded treaties. The limitations of treaties make them less desirable for the task at hand. They take a long time to negotiate, and dealing with tricky problems about the desired scope of the treaty and definitions of terms (like "space weapon") would be extremely contentious. Something in between a formal treaty and an indefinite extension of the existing legal regime has the best chance to enhance space security in the near term. This option enjoys wide support in the US and around the world. As General Kevin P. Chilton stated in answer to a written question prior to his confirmation as head of US Strategic Command, "I think as a government, we should examine the potential utility of a code of conduct or 'rules of the road' for the space domain, thus providing a common understanding of acceptable or unacceptable behavior within a medium shared by all nations."[23] Similarly, the European Parliament's recently passed resolution on space and security asked European Union member states to "explore the possibility of developing legally or politically binding 'rules of the road' for space operators."[24] Rules of the road for space are often proposed in the form of a code of conduct for responsible space-faring nations.

Rules of the road in the form of a code of conduct have several advantages. In a code of conduct, national authorities can make their own determinations about possible violations of norms. It may be possible to avoid linking a code of conduct for space to missile defense and other thorny issues, allowing negotiations to proceed more quickly.

The most important component of this code of conduct would be a pledge to refrain from harmful interference with space objects. A norm against harmful interference with satellites would clearly establish a norm, lay out "irresponsible" actions, and facilitate responses to violators of the norm. Focusing on harmful actions, rather than on the weapons used to commit them, would ease the problems associated with defining and verifying the absence of space weapons. It would also address the worst aspect of unrestrained ASAT capabilities, their tendency to create thousands of pieces of orbital debris when tested or used. The absence of destructive ASAT tests would greatly ease the tasks of debris mitigation and space traffic management. Finally, this concept would fill a lacuna in the existing treaty regime, shore up the norms against harmful interference with satellites, clarify irresponsible behavior,

and facilitate the isolation and punishment of bad actors.

New diplomatic initiatives may fail, but they ought not to fail for want of trying. If diplomacy is the primary element of a space assurance strategy, as it has been for most presidents, the US can still maintain the capacity to strike satellites using the latent capabilities of existing systems. Space assurance is best served by relying on diplomacy and defensive measures, while keeping offensive measures in reserve.

Conclusion

A space assurance strategy which focuses on diplomacy and purely defensive measures is the most likely to provide for space assurance. Diplomacy can establish and reinforce norms. In doing so, it lays the ground work for responses to irresponsible actions. Defensive measures can support diplomacy while also reducing at the margins the likelihood that attacks on satellites can disrupt their functionality. They also send a message that attacks are less likely to succeed and more likely to provoke a punitive response. The final component, offensive hedging, can also play a useful role if properly constrained. President Eisenhower called for ASAT research "as an insurance policy against possible hostile activities in space."[25] This should be the guiding precept of the offensive hedging strategy of tomorrow. Given the recent resurgence of ASAT testing in space and the hints that other nations are preparing to respond in kind, a near-term limit on this behavior would be ideal, especially because the number of countries with the latent capability to attack satellites is expanding. In this context, continuing to ignore the potential of diplomacy to contribute to space assurance seems untenable. What is needed is a reversion to a traditional, time-tested approach to space assurance.

Notes:

[1] US Department of State, Limited Test Ban Treaty, http://www.state.gov/t/ac/trt/4797.htm; US Department of State, Outer Space Treaty, http://www.state.gov/t/ac/trt/5181.htm.

[2] Samuel Black, "No Harmful Interference with Space Objects: The Key to Confidence-Building," Stimson Center Report No. 69, July 2008, http://www.stimson.org/space/pdf/NHI%20Final.pdf.

[3] National Security Planning Board, "Draft Statement of Policy on US Scientific Satellite Program," NSC 5520, 20 May 1955, in Stephanie Feyock, ed., *Presidential Decisions: NSC Documents* (Washington, DC: The George C. Marshall Institute, 2006).

[4] National Security Council, "US Policy on Outer Space," NSC 5918/1, 17 December 1959, in Stephanie Feyock, ed., *Presidential Decisions: NSC Documents* (Washington, D.C.: The George C. Marshall Institute, 2006).

[5] James Clay Moltz, *The Politics of Space Security* (Stanford, CA: Stanford University Press, 2008), 98.

[6] Dean Rusk, NSC Action 2454, 2 July 1962, in Stephanie Feyock, ed., *Presidential Decisions: NSC Documents* (Washington, DC: The George C. Marshall Institute, 2006).

[7] Ibid., 258.

[8] Raymond L. Garthoff, "Banning the Bomb in Outer Space," *International Security* 5, no. 3 (Winter 1980-1).

[9] Outer Space Treaty, Articles I and III, http://www.state.gov/t/ac/trt/5181.htm.

[10] Brent Scowcroft, "US Anti-Satellite Capabilities," NSDM 345, 18 January 1977, in Stephanie Feyock, ed., *Presidential Decisions: NSC Documents* (Washington, DC: The George C. Marshall Institute, 2006).

[11] Jimmy Carter, "Arms Control for Anti-satellite (ASAT) Systems," Presidential Directive/NSC-33, 10 March 1978, in Stephanie Feyock, ed., *Presidential Decisions: NSC Documents* (Washington, DC: The George C. Marshall Institute, 2006).

[12] Ronald Reagan, "National Space Policy," NSDD-42, 4 July 1982, in Stephanie Feyock, ed., *Presidential Decisions: NSC Documents* (Washington, DC: The George C. Marshall Institute, 2006).

[13] National Science and Technology Council, "National Space Policy," fact sheet, 19 September 1996, http://www.globalsecurity.org/space/library/policy/national/nstc-8.htm.

[14] "Executive Summary," in Report of the Commission to Assess United States National Security Space Management and Organization (Washington, DC: Commission to Assess United States National Security Space, 11 January 2001), 12.

[15] Maj Michael A. Toraborelli, "The 2nd Space Operations Squadron: Transforming Operations," *High Frontier* 4, no. 3 (May 2008).

[16] Lt Col Jon M. Anderson, "Military Positioning, Navigation, and Timing: Strategic Challenges and Opportunities," *High Frontier* 4, no. 3 (May 2008).

[17] Paul Marks, "Pentagon Wants Laser Attack Warnings for Satellites," *NewScientist.com*, 28 May 2008, http://technology.newscientist.com/article/dn14002-pentagon-wants-laser-attack-warnings-for-satellites.html.

[18] Paul Stares, *The Militarization of Space: US Policy, 1945-1984* (Ithaca, NY: Cornell University Press, 1985), 120.

[19] Stares, 123.

[20] Baker Spring, "Congress's SDI Cuts Deserve a Bush Veto," Executive Memorandum #243, 19 July 1989, http://www.heritage.org/Research/NationalSecurity/EM243.cfm.

[21] Stares, Appendix II, Table 2, 262; 206-7.

[22] Ibid., 209.

[23] General Kevin P. Chilton, "Advance Questions for General Kevin P. Chilton, USAF: Nominee for Commander, United States Strategic Command," 7 September 2007, http://armed-services.senate.gov/statemnt/2007/September/Chilton%2009-27-07.pdf.

[24] European Parliament, *Resolution of 10 July 2008 on Space and Security*, 10 July 2008, http://www.europarl.europa.eu/sides/getDoc.do?pubRef=-//EP//TEXT+TA+P6-TA-2008-0365+0+DOC+XML+V0//EN&language=EN.

[25] Stares, 106.

Mr. Samuel Black (BA, Government and Politics, University of Maryland-College Park; MPP, International Security and Economic Policy, University of Maryland-College Park) is a research associate at the Stimson Center, where he works in the Space Security and South Asia programs. He is responsible for research and analysis on a range of security policy and budgeting matters; substantive editing and writing; and project management and reporting. Black recently authored the Stimson Center Report "No Harmful Interference with Space Objects: The Key to Confidence-Building." He presented a version of the report at a United Nations Institute for Disarmament Research conference entitled "Security in Space: The Next Generation." Prior to joining the Stimson Center, Black served as a research assistant at the Center for Defense Information, where he focused on Space Security and Missile Defense issues. He is a Presidential Management Fellowship Finalist for 2008, and was awarded the Capt William P. Cole III Peace Fellowship by the University of Maryland's School of Public Policy.

Probability of Survival

Col Lee W. Rosen, USAF
Director, Counterspace System Group
Space Superiority Systems Wing
Los Angeles AFB, California

Lt Col Carol P. Welsch, USAF
Director of Engineering
Space Superiority Systems Wing
Los Angeles AFB, California

Was 11 January 2007 the modern day equivalent of the "shot heard round the world" or just another day when the US ignored the precipitous rise of China as they demonstrated their direct ascent antisatellite weapon (ASAT) capability? Was the 21 February 2008 downing of a crippled US satellite by the US Navy a diving catch to protect the citizens of the earth, or a response to the Chinese? Regardless of the answers to these questions, perhaps the ultimate homage and recognition that space has become a contested warfighting medium was the recent US Air Force recruiting video showing an enemy missile slamming into an orbiting US satellite.

The case for protecting these on-orbit crown jewels has never been more glaring, yet the US has done precious little to bolster its defensive posture in space. This article outlines one small step in bridging this precarious vulnerability gap, focusing primarily on satellite self-protection, and the concrete first steps that must be taken to protect the next generation of US satellites. This journey will take years to complete, and many other materiel and non-materiel solutions will have to be put in place, but we must start today. The holistic approach to space protection must also include a more robust and integrated space situational awareness (SSA) capability, a declarative US space protection policy, as well as our proposal for developing a common product line of standardized, tactical awareness, attribution, and protection capabilities.

The case for our protecting our space assets has been established throughout the history of other mediums (land, sea, air, cyber) and by a recognition from several key leaders that space is now a contested environment. Many analogies have been made to freedom of action on the high seas and freedom of action in space. Much of US space policy, from the return of de-orbited space objects to the treatment of foreign astronauts, is based on treaties and customs of the high seas. As economic dependence on the sea for trade and commerce grew, the need to protect that valuable instrument of national power grew commensurately. The great navies of Europe during their colonial periods were a testimony to their commitment to protection.

This same commitment to protecting our freedom of action in space and recognition that space is a contested environment has been emphatically voiced by US leadership. The president's 2006 US National Space Policy states, "The United States considers space capabilities—including the ground and space segments and supporting links—vital to its national interests. Consistent with this policy, the US will: preserve its rights, capabilities, and freedom of action in space; dissuade or deter others from either impeding those rights or developing capabilities intended to do so; take those actions necessary to protect its space capabilities; respond to interference; and deny, if necessary, adversaries the use of space capabilities hostile to US national interests."[1] General C. Robert Kehler, commander of Air Force Space Command (AFSPC) commented, "As I look into the future, I see a time when AFSPC must be prepared to operate and deliver its space capabilities in a contested environment … We saw some of that evidence when the Chinese tested their ASAT and reminded the whole world that there are capabilities that can threaten our space systems."[2] Protecting our freedom of action in space is vital to our national informational, economic, and military security.

Given our dependence on space systems, space protection must be addressed at the strategic, operational, and tactical levels. Questions at the strategic level abound. The salad days of space as a peaceful sanctuary were never real. From Sputnik to Shuttle, Corona to Operationally Responsive Space, the so-called militarization of space has been with us since its inception. Yet, we have no rules of engagement for how we operate in that warfighting medium. How would the US respond to an attack on one of its satellites?

If we look at the history of airpower, how much national treasure was poured into penetrating Soviet airspace, or protecting our Airmen against the world's most complex integrated air defense systems? The US would never send its aircraft into a known high-threat environment unprotected, yet we send our spacecraft in every 90 minutes. This argument seemingly breaks down given the fact that our spacecraft do not put humans in harms way. But what about the soldier that depends on satellite communications to keep him safe? And if US ships in international waters and US Embassy's on foreign soil are considered US sovereign territory, then what are US satellites considered? If US satellites are considered sovereign territory, how do we respond to an attack on US sovereignty? Strategic space protection starts with effective policy to deter attacks against US space systems. The US must clearly articulate a declarative policy stating that an attack on a US asset constitutes an attack on US sovereignty. This policy must be backed by a concerted effort protecting all US space assets, whether they are military, civil, allied, or commercial satellites carrying US government information.

The US cannot depend on strategic policies alone to deter attacks against US space systems and must consider operational and tactical approaches to providing space protection. The first mile of the protection road starts with situational awareness. SSA has ascended to the status of a buzzword in the space com-

munity. Everyone seems to know we do not have enough of it, desperately need more of it, and think that throwing money at the "SSA problem" will solve all our space control woes. Air Force doctrine says SSA is "the knowledge and intelligence that provides the planner, commander, and executor with sufficient awareness of objects, activities, and the environment to enable course of action development."[3] SSA alone is not protection. Protection involves both the "to know" of SSA, as well as the "to act" part of defensive counterspace. As such, SSA is a means to the ends of freedom of action in space. Yet, we do not treat it this way. Today, we seem to do SSA for SSA's sake. The reason that the Joint Space Operations Center (JSpOC) exists today is not to "do SSA." It exists to provide the Joint Functional Component Command for Space (JFCC-Space) credible options to preserve freedom of action in space. We must ensure the JFCC-Space not only knows what is happening on-orbit, but has time to act. The observe, orient, decide, and act loop applies equally in the vacuum of space as it does in the atmosphere.

More SSA does not guarantee freedom of action, nor is it necessarily "better" SSA. If we look at the US space surveillance network today, we see a system built out of Cold War necessity that has not aged gracefully. The network today consists of several stovepiped point-solutions that are not well integrated. AFSPC's interim SSA architecture seeks to modernize and integrate those systems in a net-centric, service-oriented, and rapid prototyping environment. The first dollar proposed to be spent in that architecture is not on a new sensor; it is on using what we have today more effectively. The partnership of programs being developed by the Space and Missile Systems Center (SMC) and the Electronic Systems Center is a step in the right direction in providing the means of true, decision quality SSA for the JFCC-Space. Integrated SSA (ISSA—net-centric, modernized tools for the JSpOC), Rapid Attack Identification Detection and Reporting System Block 20 (threat warning and course of action development), space command and control (C2) (user defined operating picture and connection to the global information grid), and JSpOC 3.0 (the next-generation JSpOC) are well on their way to filling the foundational need for true integrated SSA. But SSA is only one piece of the protection puzzle. The US must change the way it designs weapon systems operating in the medium of space.

The final part of this three legged protection stool to be discussed are tactical protection capabilities. Protecting space is hard and costly. While space-based protection is necessary, it is not ideal. The space kill chain timelines are extremely trying and it is challenging to stay ahead of the counter-counter measure race with an adversary once on orbit. Driving protection timelines as far to the left (well before the shot is taken) is key. With space-based protection smart decisions need to be made very early on in the program.

Aircraft have operated in a contested environment since the dawn of airpower, and as a result, aircraft system engineers have long considered survivability as a key element in combat aircraft system designs. Aircraft survivability is now a mature, dedicated field of study complete with professional journals and conferences, and a joint service supporting program office.[4] The national security space community needs to do the same and apply similar approaches to space systems. This aircraft survivability methodology measures survivability as the statistical probability of surviving the attacker's complete kill chain. The effectiveness of the kill chain can be quantified as a function of the target's susceptibility to an attack (i.e., what is the probability that the target can be detected, tracked, and hit?) and the target's vulnerability (i.e., if hit, what is the probability the target will be killed?).

Applying this model to space systems would enable the space system engineer to objectively determine optimum solutions for enhancing a space system's survivability. Through rigorous analysis, trade studies can be accomplished between various protection approaches and vulnerabilities can be minimized.

Analysis alone, however, won't provide space protection. Implementing space protection starts with establishing a requirement for protection. One approach to accomplish this is to state a required minimum probability of survival for new space system acquisition programs, and document this requirement in the program capabilities description documents, perhaps even as a key performance parameter for high value space assets. Without a documented requirement, even the most well-intentioned space system acquirers cannot justify the cost, schedule, and performance impacts to their programs caused by including self-protection systems. To the survivability analyst, it would be desirable to levy a 100 percent probability of survival on all space systems in all threat scenarios since every national security space program inherently contributes significantly to national security. The reality is that the US could quickly break the national treasury trying to protect every space system against every threat. The required probability of survival for a specific space system, then, should be carefully determined based on the factors such as the criticality of the space system in a particular threats scenario and the likelihood of a particular threat. This is not an easy task since it requires understanding the impact to the joint fight of losing space systems and the complex interdependencies between systems. The aircraft community accomplishes this task through campaign level modeling. It is time for the space community to do the same. Space campaign models are needed to enable rigorous analysis and quantification of the impact of losing different space capabilities. How much does the loss of global positioning satellites affect the length of a land campaign? How does the loss of communications satellites affect a theater commander's campaign plan? Answers to these questions help the requirement community understand which systems are the highest priority to protect, and so demand a higher survivability requirement.

To determine the right probability of survival for specific space systems and to evaluate the overall effectiveness of space architectures, the national security space community must nurture a space survivability analytical field of study. Space survivability analysts are necessary to understand a design's susceptibility and vulnerability to current and projected threats, to make trades between various design approaches, and to perform

architecture studies based on rigorous modeling and simulation. These architecture studies would ideally be based on space campaign and engagement level models, enabling the analyst to identify the most cost-effective architectures and concepts of operations for ensuring that space capabilities will be there when and where they are needed. The national security space community needs to make developing the necessary modeling and simulation tools a priority. The space community could benefit by adapting the aircraft community's approach of establishing a survivability program, the Joint Aircraft Survivability Program, to coordinate survivability efforts, fund analytical efforts, and help develop space survivability analysts.

The Space Superiority Systems Wing has invested in developing robust, analytically-based modeling and simulation tools for evaluating the performance and cost effectiveness of SSA architectures, offensive counterspace systems, and defensive counterspace systems. Tools like the Space Superiority Systems Wing's Lookout model provide the analysis capability to make these difficult, best value, cost versus performance investment decisions. Although still in development, these tools are already proving useful for providing objective analysis of new system concepts and architectures. Continued development of modeling and simulation tools, and nurturing an associated space survivability community of study, will provide space system developers the ability to determine the right level and type of protection for national security space programs.

Just as a combat aircrafts survival is dependent on having situational awareness of the battlespace, space protection is predicated on SSA. Maintaining track custody on all potential threats to all of our assets, in all orbital regimes, and providing sufficient warning time to "target" satellites to take some kind of defensive action is a difficult and costly endeavor. Much like the Navy uses a layered defense system around its carrier battle groups, the Air Force will need to set up a layered defense system around the US's most important space assets. The inner "tactical-level" layer of that protection system, on board the asset itself, must take cues from the outer layers, and have its own capability to first know if it's under attack, next be able to communicate the fact that it's in duress, have the capability to attribute the attack to an adversary, and then finally do something to protect itself.

The first of these necessary capabilities of gathering and fusing information from operational-level SSA assets to make tactical decisions, with timely command and control, is anything but trivial. The ISSA/RB-20/Space C2/JSpOC 3.0 capabilities mentioned earlier will provide the integrated SSA picture to take the operational-level raw data, and fuse it into actionable information. The rest of the puzzle (self-awareness, communication, attribution, and protection) are being developed by the program known as Self-Awareness Space Situational Awareness (SASSA).

The vision for the SASSA program is to produce a common product line of on-orbit awareness, attribution, and in some future instantiation, protection capabilities that are "plug and play" compatible and minimally obtrusive to the host satellite. The SASSA demonstration program is in the initial acquisition phase to build up to two flight-ready systems. The goal of SASSA is to develop the standard for on-board awareness/attribution capability. The system will be designed to be modular, scalable, and have standardized interfaces to be backward and forward compatible with a number of bus designs and sensor designs. The vision is to be like the standard encryption gear (KG) that is carried on nearly every Department of Defense (DoD) and National Reconnaissance Office satellite. Satellite designers know up front they are mandated to carry a KG; they understand the design interface, and the resultant size, weight, and power requirements for the unit.

The heart of the SASSA standard system is the common interface unit (CIU). Picture your television set. It can plug into any US wall outlet, and has a variety of HDMI, USB, S-Video, and other connections to input other media. The CIU plugs into a number of satellite bus power/comm/data handling infrastructures (1553, spacewire, etc.) and will host a standardized, stand alone communication package, a radar warning receiver, and a laser warning receiver. All of this will be delivered in a "net-centric" data output format. But the community must not be naïve or complacent enough to think that we can stop with the SASSA demonstration.

Recognizing the need for protection, what is the most cost-effective approach to provide protection systems or packages for national security space programs? Efficiencies can be gained by using a consolidated acquisition source which can provide protection solutions with the ability to tailor different solutions for different missions. This approach avoids each space program having to develop their own, unique space protection packages and enables the space system program directors to remain focused on their primary mission. It also achieves economies of scale provided by a common product line. The acquisition source could be responsible for development, testing, and qualifying protection packages. This same source could maintain contract vehicles on an indefinite delivery/indefinite quantity basis to simplify procurement for all programs. Think of a Space Protection "Home Depot" where program directors can turn to procure a space qualified protection package to meet their needs, along with experienced analysts and engineers to help them choose the ideal protection package. To quote the Home Depot approach: "You can do it. We can help."

An important element of the "Space Protection Home Depot" is the provision for a program to experiment with new concepts and tactics, and to demonstrate them in an operationally relevant environment before they are integrated on operational spacecraft. These demonstrations are necessary to reduce risk for operational programs by characterizing the performance and reliability of the space protection package before it is employed operationally. These demonstrations would also serve to validate space protection modeling and simulation tools.

A dedicated program to develop space protection packages would not replace the excellent work being accomplished by research laboratories. It would be expected that research laboratories and agencies would continue to pursue research supporting space protection technologies. However, a dedicated program is necessary to pull promising technologies from the

labs and perform on-orbit demonstrations. This function is partially accomplished by the Air Force's Space Control Technologies Program (to pull technology from the laboratories) and the DoD Space Test Program (to provide access to space). However, both these programs are inadequately resourced to accomplish the needs of space protection. A reliable funding level must be provided which allows a steady pipeline of technology maturation, ground testing, on-orbit demonstrations and evaluations. A deliberately planned, regularly scheduled, small satellite launch dedicated to space protection demonstrations is a must.

The ideas presented here are a vision of the future, but there are steps we can take today to work towards this vision without new programs or policies. The SMC Space Protection Forum stood up this year with the mission to facilitate communications between force enhancement programs and the Space Superiority Systems Wing. This unique forum provides an avenue to ensure programs' space protection requirements are well-understood and to develop the right protection solutions.

The requirement to provide on-board protection capabilities for US satellites is as apparent as the emerging threats. Future programs of record birthed from the SASSA demo must be put in place to operationalize SASSA's awareness, attribution, and communications capabilities, and develop effective, broad-spectrum countermeasures to emerging threats. This long-term program should deliver that common, standardized product line of reliable, affordable, ISSA-compatible capabilities, along with the requisite C2 system for protecting all critical US, and potentially allied spacecraft.

Today the Chinese are merely testing ASAT weapons. Will the US be ready when China operationally deploys their ASAT weapons? We know how we want a future space campaign to look: an ASAT attack is immediately detected by a robust network of sensors, the sensor data is integrated and presented to the commander in intuitive fashion, along with a menu of possible courses of action. The commander selects a course of action while self-protection packages activate. The ASAT misses its target. Probability of survival: 100 percent.

Notes:

[1] White House, "US National Space Policy." Office of Science and Technology Policy, 31 August 2006, http://www.ostp.gov/html/US%20National%20Space%Policy.pdf.

[2] A1C Wesley Carter, "Kehler: AFSPC has been entrusted with a national mission," 15 January 2008, http://www.vandenberg.af.mil/news/story.asp?id=123082331 (accessed 8 September 2008).

[3] Air Force Doctrine Document 2-2.1, *Counterspace Operations*, 2 August 2004, 51.

[4] The Joint Aircraft Survivability Program funds joint technological and analytical tools for enhancing survivability of aircraft. Dr. Joel Williamson, "Satellite Vulnerability to Direct Ascent KE ASAT: Applying Lessons Learned from NASA, Missile Defense, and Aircraft Survivability Programs," *Aircraft Survivability*, Summer 2008, http://www.bahdayton.com/surviac/asnews/AS_Summer_2008.pdf (accessed 30 August 2008), 25.

Col Lee W. Rosen (BS, Human Factors Engineering, USAFA; MS, Space Studies, University of North Dakota; MS, Logistics Management, AFIT) is the director of the Counterspace Systems Group, Space Superiority Systems Wing, Space and Missile Systems Center (Air Force Space Command) at Los Angeles AFB, California. Colonel Rosen's first assignment was as a missile maintenance officer with the 321st Missile Wing, Grand Forks, North Dakota. In 1991, Colonel Rosen was selected to attend the Air Force Institute of Technology at Wright-Patterson AFB, Ohio. Upon graduation from AFIT, he was assigned to the Launch Programs Office, Upper Stages Program at the Space and Missile Systems Center, Los Angeles AFB, California. Colonel Rosen was part of the initial cadre of the National Polar-orbiting Operational Environmental Satellite System, Polar-orbiting Operational Environmental Satellite System, DMSP Program Office. Colonel Rosen attended Undergraduate Space and Missile Training in 1997 and was awarded the Space Operations career field specialty. He was assigned to the Pentagon in 1998 where he served various positions culminating with executive assistant to the director of the NRO. In 2001, Colonel Rosen moved to Vandenberg AFB to be the director, Evolved Expendable Launch Vehicle Program and later the commander of the 4th Space Launch Squadron. In 2006 he joined the Superiority Systems Wing first as the program control chief, and now serving as the director of the Counterspace Systems Group.

Lt Col Carol P. Welsch (BS, Aeronautical Engineering, Rensselaer Polytechnic Institute; MAS, Aerospace Management, Embry-Riddle University) is the director of engineering for the Space Superiority Systems Wing. Colonel Welsch was commissioned as a second lieutenant through the Air Force ROTC program in May 1988. Her career includes a variety of assignments as an engineer in space acquisition, space operations, flight test, and intelligence fields. Colonel Welsch temporarily left the engineering field to serve as an Air Force Legislative Fellow to the Office of Senator Wayne Allard. As a member of Senator Allard's staff, she was responsible for all homeland security issues and assisted on military and space legislative issues. She followed this fellowship with assignments to the Air Staff Directorate of Space Operations, and the Office of Legislative Liaison where she served as the Secretary of the Air Force's focal point for all Air Force space legislative issues. Colonel Welsch also served as the director of the Space Development Group, Space and Missile Systems Center (SMC), Kirtland AFB, New Mexico. In this capacity, she was responsible for the Department of Defense Space Test Program, the Multi-Mission Satellite Operations Center acquisition program, and SMC support to the Joint Operationally Responsive Space office. Colonel Welsch is a graduate of the Air War College at Maxwell AFB, Alabama.

Moving Beyond SSA: An Attribution Architecture for Space Control

Maj Wallace "Rhet" Turnbull, USAF
Lead, Simulation Engineering, Plans and Integration
Joint Functional Component Command for Global Strike
US Strategic Command
Offutt AFB, Nebraska

Setting the Context

Since taking an early lead in the space race, the US Air Force has enjoyed both freedom *of* action and freedom *from* action in space. The Air Force's space doctrine seeks to protect these freedoms while also being able to deny an adversary the same freedoms.[1] For decades, this doctrine has been underwritten by superior US space capability. However, the blanket of superiority that provides US space security is starting to show signs of wear at the same time as the nation grows increasingly more reliant on the application of space power to win its wars. The space club is no longer as elite as it once was and the proliferation of space technology to non-traditional space actors promises to shrink the asymmetric US space advantage. Additionally, new members of the space club may not practice traditional restraints regarding the weaponization of space, a fact well illustrated by China's unannounced antisatellite (ASAT) test in 2007.

The high-profile test of a direct ascent ASAT by China served as a harsh reminder that space power can be held at risk by a determined adversary. As a result of the Chinese ASAT test, the Air Force has shown a renewed interest in defensive counterspace capabilities. The Air Force Research Laboratory, for example, has proposed a concept dubbed Autonomous Nanosatellite Guardian for Evaluating Local Space (ANGELS) that would employ bodyguard satellites to escort key systems.[2] The ANGELS satellites would be used to inspect host spacecraft for damage or to provide local situational awareness. A logical extension of the ANGELS concept would be a defensive escort that could intercept a would-be attacker. While such defensive systems may someday provide limited protection against certain threats, the unique physics of a space attack will always favor the attacker. Flying a spacecraft is quite different than flying an aircraft; unlike aircraft in a dogfight, a spacecraft has a very small maneuver envelope and it is unlikely that a satellite under attack could evade an attacker without significant warning.[3] Such warning is, of course, dependent on knowing the attacker's position, capabilities, and intent—no small feat and one which requires exquisite space situational awareness (SSA).

From Surveillance to Awareness

The United States collects SSA data from a loose confederation of systems collectively known as the Space Surveillance Network (SSN). The SSN is comprised of ground-based optical and radar sensors and a single space-based optical sensor. Additional SSA data is gathered by various environmental sensors on individual spacecraft but such data is rarely fused and correlated with other SSN data in any meaningful manner. The SSN sensors observe man-made objects as they traverse through space and collect data that is then used to compute each object's orbital path, allowing the object's future position to be predicted.[4] This process is called space surveillance, the end result of which is a database of tracked objects known as the space catalog.

The current space catalog tracks about 17,000 man-made objects 10 centimeters (cm) in diameter or larger.[5] Due to sensor availability, the SSN cannot continuously track every space object. Instead, the SSN uses the computed orbit to predict an object's future position then periodically performs a spot check to update the orbital track. Some objects, such as high interest spacecraft, are checked more frequently than others. As a result, the SSN might lose track on an object that unexpectedly moves between updates. Once track is lost, it can take days or even weeks for the SSN to find the object and reestablish track. This operational constraint could be exploited for counterspace purposes; for example, by an orbiting ASAT that masqueraded as space debris before maneuvering to a target.

The SSN's historical role has been to monitor space debris for collision avoidance purposes. While the SSN has performed this role commendably, limitations of the current system could have grave consequences in a contested space environment. These limitations have long been known, but in the absence of a credible space threat, the status quo was deemed acceptable. Air Force leaders are, however, pushing to expand SSN capabilities and a handful of enhancements and new systems are collectively moving US space control capabilities from a paradigm of *surveillance* to that of space situational *awareness*. For example, the planned upgrade of the Air Force Space Surveillance System, also known as the Space Fence, and the Space-Based Space Surveillance (SBSS) system, currently under development, will both add significant enhancements to the SSN and improve detection limits for small satellites in higher orbits as well as increase timeliness of space tracking data.

A New Space Race

While the Air Force is taking steps to build a more robust SSA capability, rapid technological advances are accelerating the rate at which space capability is proliferated to other space actors. The result is a race between satellite systems and space surveillance systems. Satellite technology is constantly evolving and does so at a faster pace than space surveillance systems which have multi-decade life-cycles. Nowhere is this more ev-

ident than in the revolution taking place in very small satellites which can have a life-cycle as short as nine months and can be built for a fraction of the cost of traditional spacecraft.[6]

Since Sputnik, the first satellite, was launched in 1957, the average satellite size has steadily increased. Sputnik was only 84 kilograms (kg) while a modern military communications satellite, such as the Advanced Extremely High Frequency (AEHF) system, can weigh as much as 6,000 kg.[7] This trend is the result of a number of factors such as launch cost, development cost, and an increase in requirements. However, technological advances are reversing this trend and there is growing interest in making spacecraft as small as possible. This is especially true among non-traditional space actors who value smaller satellites because they lower the cost of entry into the space club.

The spacecraft industry has developed a lexicon, shown in table 1,[8] for describing satellites of various sizes, which includes minisatellites, microsatellites, nanosatellites, picosatellites, and femtosatellites.[9] Since the early 1990s, satellites in the microsatellite class (10 to 100 kg) have steadily gained popularity, spurred by advances in microelectronics. Because small satellites generally cost less to build and launch than traditional satellites, they are more accessible to nations that otherwise might not invest in space technology. This phenomenon has fueled a growing small satellite industry. Estimates indicate that over 30 nations have conducted small satellite programs and even more are planning them.[10]

Category	Mass (kg)	Cost (USD)
Large satellite	>1000	0.1-2B
Medium satellite	500-1000	50-100M
Minisatellite	100-500	10-50M
Microsatellite (microsat)	10-100	2-10M
Nanosatellite (nanosat)	1-10	0.2-2M
Picosatellite (picosat)	0.1-1	20-200K
Femtosatellite (femtosat)	<0.1	0.1-20K

Table 1. Satellite Categories by Mass and Approximate Cost.

Although microsatellites remain a popular option for both governmental and non-governmental operators, interest in even smaller spacecraft has continued to grow. Consumer demand for smaller electronic devices such as mobile phones has driven advances in miniature electronics, microelectromechanical systems, and nano-technology. These multi-use technologies have been readily adopted by the small satellite industry, enabling satellites to shrink even further, which in-turn has permitted nanosat and picosat-class satellite missions.

Over 30 nanosat missions, ranging from 1 to 10 kg, have flown worldwide since 2000 and many more are planned. The missions have validated a wide range of payloads from earth observation to communications systems and capabilities which are constantly improving. Consider for example, the Canadian-built CanX-4 and CanX-5 missions, from the University of Toronto's Space Flight Laboratory. The CanX missions, planned for launch in 2008, will demonstrate precision formation flying, rendezvous, and inter-satellite crosslink communications in a 7 kg spacecraft measuring less than 20 cm across.[11] It is a small leap to imagine using such a system as an orbiting ASAT which could be used to attack or monitor other satellites. Indeed, notional systems such as the Deployable Monitoring Nano-Satellites have already been proposed to do this.[12]

Nanosats have demonstrated that considerable functionality can be packed into small, inexpensive spacecraft and technology is enabling even smaller picosat systems. Over 20 picosat systems weighing less than a kilogram have flown since 2,000 and at least two dozen missions are in development.[13] These spacecraft have demonstrated capabilities similar to those of microsat and nanosat missions including imaging sensors, precision attitude control, and high-bandwidth communications. Usually measuring less than 10 cm across, it is possible that many picosat systems could operate unobserved by the SSN, particularly in higher orbits such as the medium-Earth orbit where the Global Positioning System (GPS) constellation operates or the geosynchronous orbit where many military communication satellites are stationed. Additionally, an adversary could take active measures to deploy such systems covertly such as hitchhiking on civilian systems or employing low-observable technologies to reduce a spacecraft's signature, thereby decreasing the ability of the SSN to track it.

With over 50 missions flown to date, very small satellites have moved from the realm of science fiction to that of operational reality. Flight-proven nanosat and picosat technologies are likely mature and widely proliferated enough to enable a willing adversary to field orbital ASATs in the near term. These small orbital ASATs could be developed or procured for relatively small budgets, making them a more attractive option than expensive and complex direct ascent missile ASATs such as the system demonstrated by China.

Small satellite technology will continue to advance and some researchers believe that even smaller femtosat spacecraft, measuring a centimeter or less across, are possible. For example, Maj David Barnhart has proposed a fully-functional satellite constructed from a single integrated circuit chip dubbed SpaceChip.[14] Researchers at Cornell University have similarly proposed a spacecraft design that utilizes a novel propulsion scheme and measures only a few millimeters across.[15] Current femtosat designs would do little more than demonstrate feasibility but technological drivers will continue to shrink spacecraft components and systems and it is possible that femtosat sized systems could be operational in the not-too-distant future.

Architecture as a Policy Enabler

The specter of inexpensive and widely proliferated ASAT systems on the horizon should cause Air Force leaders to consider the implications for space control doctrine and systems. Would-be ASAT builders will maintain an advantage over surveillance and awareness systems for the foreseeable future. Small satellite builders have or will have the technological means to rapidly develop increasingly smaller satellites at decreasing costs. Defense against such systems, especially without comprehensive SSA, will remain extremely challenging.

In the absence of a robust defensive capability, the United

States must continue to depend on deterrence to protect its freedom of action in space. The US National Space Policy is predicated on the ability to "dissuade or deter" adversaries from impeding freedom of action.[16] In order for this policy to succeed, would-be attackers must believe that their actions will be detected and accurately attributed, for without such knowledge, the US cannot project a credible deterrent threat. However, in a future environment where an adversary can field very small and possibly undetectable ASAT systems, this deterrent power is negated, allowing the adversary to act with impunity. For without reliable attribution, it would be nearly impossible to distinguish a space attack from a satellite malfunction. Mark Berkowitz, former assistant deputy under secretary of defense for space policy, has noted that this capability gap constrains both "policy and operational responses."[17]

One way to address the policy gap is to build an attribution architecture for space control. The *attribution architecture* must be more comprehensive than the current SSN and other SSA systems; it must be capable of producing an "indisputable chain of evidence" when a hostile event occurs, thus lifting current constraints and providing national leaders with response options.[18] As General Kevin Chilton, then commander, Air Force Space Command, emphasized in a 2007 speech, "None of the things we've been able to do as a nation … could be brought to bear without attribution, and attribution is absolutely key."[19]

The proposed attribution architecture must truly be just that—a holistic architecture, designed as a policy enabler, and not merely a better SSN. It should be a comprehensive space control architecture, utilizing a layered approach to space security. These layers would include, at a minimum, SSA, defense, attribution, robust space systems, and rapid reconstitution capability.

Barring significant leaps in defensive technology, space defense will remain difficult, though escort systems such as ANGELS may provide limited protection for high-value systems. Even if defense is not possible, such systems would still be valuable for providing enhanced situational awareness. Other developmental systems such as the Self-Aware Space Situational Awareness concept, which will put a sensor suite akin to a threat warning receiver onboard spacecraft, will also enhance SSA—a prerequisite for attribution. The Air Force should accelerate the fielding of such programs but care should be taken to ensure that they are part of a space control framework and not just short-term solutions.

Other possible improvements for the attribution architecture include higher resolution ground radars and fielding space-based optical systems such as SBSS. However, to keep pace with the rapidly evolving threat from very small satellite systems, such traditional solutions may be insufficient and the Air Force should resolve to develop technologies that can locate, identify, characterize, and track very small space systems across all orbital regimes.

A critical part of attribution is not just identifying what happened, but also identifying who did it. In addition to tracking space objects—the domain of today's SSN, the attribution architecture will need to characterize and identify the objects, determine capabilities and even intent, and trace the objects back to the country of origin by providing track custody from launch to reentry. This will require significantly more data than the SSN utilizes today. In order to accomplish this, the attribution architecture will require the ability to fuse and correlate a wide range of data from disparate sensors. Current programs such as Integrated SSA, Space Threat Awareness and Characterization Service, and the Rapid Attack Identification, Detection and Reporting System are steps in the right direction.

In addition to improving detection and attribution, the Air Force should also focus on improving the robustness of space systems.[20] Today's military satellites are usually large, expensive systems that are essentially sitting ducks. They are easy to track, even by amateur space watchers, and difficult to defend. Current satellites systems take years to build and are costly to replace. As satellite components shrink and small satellite systems grow in capability, it is possible that at least some of the capability of these monolithic military systems could be distributed among many smaller satellites. As result, the system could be designed to degrade gracefully instead of failing catastrophically. Another possibility, currently being explored by the Defense Advanced Research Projects Agency, is a fractionated spacecraft concept that distributes functions across a cluster of small spacecraft making the system easier to repair and more resilient to attack.[21]

Even with the best defenses, SSA, and robust satellite systems, it is possible that an adversary could still successfully impair or destroy US space systems. In such an event, the US must possess the ability to quickly reconstitute warfighter capability. There is an important distinction to be drawn here between *space* capability and *warfighter* capability—the focus must be on meeting warfighter requirements, not on fielding specific systems. Efforts such as Operationally Responsive Space, which seeks to develop small and inexpensive spacecraft capable of being quickly launched, will help fulfill this need, but other possibilities include high-altitude long-endurance aerial systems and near-space systems. The Air Force must be willing to cast a wide technology net in order to identify the reconstitution systems that best meet warfighter needs.

It is clear that the United States is developing capabilities that can be applied across all layers of a space control architecture. Courageous leadership and vision are needed to ensure that these efforts are developed as pillars in a comprehensive architecture and not merely as stand-alone cylinders of excellence. Air Force leaders must give consideration to the rapidly

The Air Force should accelerate the fielding of such programs but care should be taken to ensure that they are part of a space control framework and not just short-term solutions.

evolving nature of the space threat so that system capabilities can evolve accordingly. Unfortunately, many of the systems mentioned in this article are behind schedule and under-funded; in the fiscally and technologically constrained environment in which today's Air Force operates, this will require tough choices and trade-offs. One thing seems certain though: regardless of what choices the Air Force makes, other space actors will develop the capability to hold US space systems at risk.

Conclusion

Our nation clearly faces an uncertain future where historical space doctrine may be inadequate to guarantee continued space superiority. The Air Force must reevaluate the assumption that space is a sanctuary and help the nation craft a space policy capable of dealing with non-traditional space actors. While it would be foolhardy to give up on the notion of space defense, it would also be unwise to assume that new space actors, who have demonstrated both the will and the technical means to challenge US space superiority, will be deterred by the same means as old adversaries. An attribution architecture for space control lays a solid foundation upon which national leaders can build a viable space policy.

Notes:

[1] Air Force Doctrine Document (AFDD) 2-2-1, *Counterspace Operations*, 2 August 2004, 5.

[2] Paul Rincon, "Military satellites 'may get stealthy'," *BBC News*, 21 February 2008, http://news.bbc.co.uk/2/hi/science/nature/7257666.stm (accessed 3 March 2008).

[3] David Wright, Laura Grego, and Lisbeth Gronlund, *The Physics of Space Security: A Reference Manual* (Cambridge, MA: American Academy of Arts and Sciences, 2005), 153.

[4] United States Strategic Command, "USSTRATCOM Space Control and Space Surveillance Fact Sheet – 25 Feb 08," 1, http://www.stratcom.mil/fact_sheets/STRATCOM%20Space%20and%20COntrol%20Fact%20Sheet%20--%2025%20Feb%2008.doc (accessed 13 September 2008).

[5] Ibid., 1.

[6] Hank Heidt et al., "CubeSat: A New Generation of Picosatellite for Education and Industry Low-Cost Space Experimentation," (Proceedings of the 15th Annual AIAA/USU Conference on Small Satellites, Logan, UT, 2001), 1.

[7] David J. Barnhart, Tanya Vladimirova, and Martin N. Sweeting, "Enabling Space Sensor Networks with PCBSat," paper presented at 21st Annual AIAA/USU Conference on Small Satellites, Logan, UT, August 2007, 7; Department of the Air Force, *The Air Force Handbook 2007* (Washington, DC: HQ Air Force, 2007), 33.

[8] David J. Barnhart, Tanya Vladimirova, and Martin N. Sweeting, "Very-Small-Satellite Design for Distributed Space Missions," *Journal of Spacecraft and Rockets* 44, no. 6 (November-December 2007): 1297.

[9] The term "satellite" is often shorted to "sat" so that femtosatellite becomes femtosat, etc.

[10] SpaceSecurity.Org, *Space Security 2007* (Waterloo, Canada: Project Ploughshares, August 2007) 60.

[11] Stuart Eagleson et al., "Adaptable, Multi-Mission Design of CanX Nanosatellites," paper presented at 20th Annual AIAA/USU Small Satellite Conference, Logan, UT, August 2006, 1.

[12] Paul Rincon, "Military satellites 'may get stealthy'," *BBC News*, 21 February 2008, http://news.bbc.co.uk/2/hi/science/nature/7257666.stm (accessed 15 September 2008).

[13] Michael Thomsen home page, "Michael's List of Cubesat Satellite Missions," http://mtech.dk/thomsen/space/cubesat.php (accessed 28 March 2008).

[14] Barnhart, "Very-Small-Satellite Design for Distributed Space Missions," 1297.

[15] Justin A. Atchison and Mason Peck, "A Millimeter-Scale Lorentz-Propelled Spacecraft" (paper presented at AIAA Guidance, Navigation, and Control Conference and Exhibit, Hilton Head, SC, August 2007), 1.

[16] White House, "US National Space Policy." Office of Science and Technology Policy, 31 August 2006, http://www.ostp.gov/html/US%20National%20Space%Policy.pdf, 1-2.

[17] Marc J. Berkwotiz, "Protecting America's Freedom of Action in Space," HQ AFSPC, *High Frontier* 3, no 2 (March 2007), 17.

[18] Roger Hall, "Space Situational Awareness," speech, given at DARPATech, DARPA's 25th Systems and Technology Symposium, Anaheim, CA, August 2007, http://www.darpa.mil/darpatech2007/proceedings/dt07-vso-hall-awareness.pdf (accessed 1 November 2007).

[19] General Kevin P. Chilton, "Space Command at Twenty-Five," address, Air Force Association 2007 Air and Space Conference, Washington, DC, 25 September 2007, http://www.afa.org/events/conference/2007/scripts/Space-Chilton.pdf (accessed 16 September 2008).

[20] Massimo Calabresi, "Quick, Hide the Tanks!," *Time*, 15 May 2000, 60.

[21] William Matthews, "Cluster Solution: Fractionated Sats Could Offer Survivability, Flexibility," *Defense News*, 10 March 2008, http://www.defensenews.com/story.php?i=3413041&c=FEA&s=TEC (accessed 10 April 2008).

Maj Wallace R. Turnbull, III (BS, Astronautical Engineering, United States Air Force Academy; ME, Space Operations, University of Colorado; MA, Military Operational Art and Science, Air Command and Staff College) is currently lead, Simulation Engineering, Plans and Integration, Joint Functional Component Command for Global Strike (JFCC/GS), US Strategic Command (USSTRATCOM), Offutt AFB, Nebraska. He is responsible for developing end-to-end integrated air defense models supporting JFCC/GS mission analysis.

After commissioning through the United States Air Force Academy in 1995, Major Turnbull was assigned as a spacecraft engineer at the 4th Space Operations Squadron, Schriever AFB, Colorado. From 1999 to 2002, he served as Space Experiments Program manager at the Air Force Research Laboratory, Space Vehicles Directorate, Hanscom AFB, Massachusetts. Major Turnbull's next assignment was chief, Command and Control Development at the Space Systems Program Office, Signals Intelligence Directorate, National Reconnaissance Office, Washington, DC, where he was responsible for the development of flight and ground systems for next-generation intelligence satellites. In 2006, Major Turnbull was assigned as program manager, Rapid Attack Identification, Detection, and Reporting System Block 20, at the Space Superiority Systems Wing, Los Angeles AFB, California.

Major Turnbull is a graduate of Air Command and Staff College where he received the Air Force Space Command Space Research Award for his paper "Beyond Awareness: Moving Towards Comprehensive Space Situational Knowledge."

Fractionated Satellites: Changing the Future of Risk and Opportunity for Space Systems

Mr. Naresh Shah
Associate, Booz Allen Hamilton, Global Defense Program Lead, Defense Advanced Research Projects Agency, System F6 Program
Arlington, Virginia

Dr. Owen C. Brown
Program Manager, Tactical Technology Office
Defense Advanced Research Projects Agency
Arlington, Virginia

"[I]t is important to recognize that space missions are a 'one strike and you are out' activity. Thousands of functions can be correctly performed and one mistake can be mission catastrophic."[1]

~ Thomas Young, Chairman of the Mars Program Independent Assessment Team

"One strike and you're out." This phrase describes the unforgiving nature of space systems, be they military, civil, or commercial. Indeed, the failure of a small component or an error in a single line of software code can doom a launch, or cause the quick and complete failure of a spacecraft. In addition, the growing capabilities of other space-faring nations make it apparent that a lethal "strike" could be literal, and not just a sports metaphor. Because of the large size and significant capability of today's spacecraft, the impact of an organic failure, or a hostile act, could be devastating. In the words of former National Aeronautics and Space Administration lead flight director Eugene "Gene" F. Kranz: "Failure is not an option." Indeed, with today's large monolithic space systems, we do not have an *option to fail*, or for that matter to perform below expectations. However, the frustrating (and often overlooked) fact is that these same space systems are designed with few *options to exceed original expectations* either. A prime example is the ability to take advantage of Moore's Law by frequently upgrading computing-related capability on-orbit.[2]

Space systems today are large and capable, but also fraught with high risks and limited opportunities due to an inherent lack of *robustness* and *flexibility*. In this article, we examine how and why our space systems have evolved to this condition. We then describe a new spacecraft architecture which significantly challenges the conventional approach to space system design, *reducing risk*, and *increasing opportunity* throughout a space system's life-cycle. By implementing a fully networked distribution of space system payloads and infrastructure, this new architecture, an approach called "fractionation," can maintain, and perhaps even surpass, the capability we have grown to expect and rely on in our space systems. A new Defense Advanced Research Projects Agency (DARPA) program called System F6 strives to prove that this radical method of space system design can work.[3] If it succeeds, System F6 will enable the pervasive growth of an architectural paradigm which will produce robust, flexible, and highly capable space systems for decades to come.

The Trend Toward Large Spacecraft

"One of the things that has happened over this past half century is that the engineering and the programmatic refinements that have gone on have led us to the point where we have very sophisticated but very complicated satellites, very expensive satellites. We have invested in longer life on orbit with more multimission capabilities on a single platform because the cost and risk associated with the launch has tilted us in the direction of more capabilities on individual platforms."[4]

~ Lt Gen Michael A. Hamel, USAF, former commander of the Space and Missile Systems Center

The world recently celebrated the fiftieth anniversaries of the launch of its first and second artificial satellites—the USSR's Sputnik and the US's Explorer 1. These were small, short-lived spacecraft weighing 184 lbs (84 kg) and 31 lbs (14 kg) respectively.[5] The beep of Sputnik lasted a mere three weeks, while Explorer 1's science package relayed data for 105 days. The Juno I rocket that lifted Explorer 1 had little, if any, excess lift

TERMINOLOGY

Key Term	Definition
Risk	A state of uncertainty where some of the future possibilities involve a loss or other undesirable outcome, such as excessive cost, schedule, or inability to meet performance goals
Opportunity	*A state of uncertainty where some of the future possibilities involve improvements in performance, cost, value, schedule or other metric*
Flexibility	The ability of a system to change on demand at any time during its lifecycle
Robustness	The ability of a system to continue performing its intended function despite the introduction of an internal or external stimulus
Fragility	The tendency of complex systems to exhibit unmodeled failure modes, usually due to an unanticipated component interaction leading to a catastrophic, albeit improbable, sequence of events

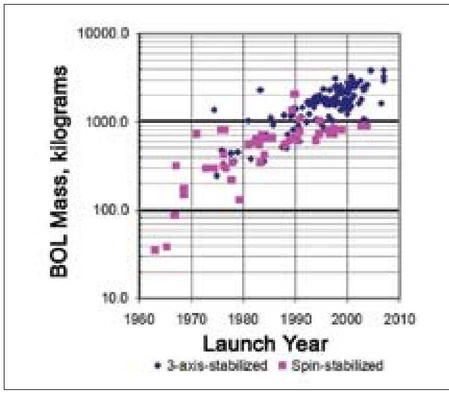


Figure 1. Beginning of Life (BOL) Mass.

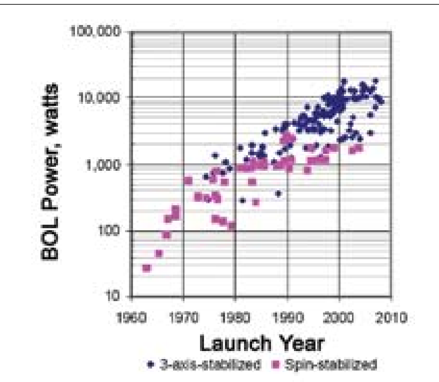


Figure 2. BOL Power.

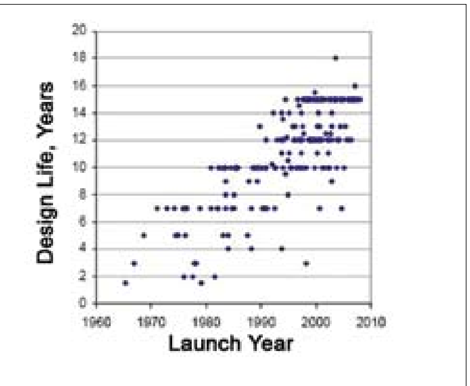


Figure 3. Spacecraft Design Life.

capacity, and stood a mere 21.2 m tall.

Advances in liquid propulsion, structures, and avionics quickly led to much larger launch vehicles. Today, the work-horse of national military missions, the evolved expendable launch vehicle, has a lift capacity in the several thousands of kilograms range, as do the widely-used commercial vehicles Ariane V, Sea Launch, and Proton. The large lift capacities of modern launch vehicles are necessary to accommodate modern spacecraft, which continue to grow in both size and power. Figure 1 shows the trend in launch mass of commercial geosynchronous communications spacecraft over the last five decades. Figure 2 shows a similar trend in power producing capabilities for these satellites.[6] Finally, figure 3 shows the trend in increased lifetimes for communications satellites. National security spacecraft can be inferred to have similar trends in size, mass, and lifetimes, since the heritage of many commercial and military buses are common.[7] Why this trend? We know that technological advances in space power, structures, thermal management, and other areas enabled (but did not cause) the growth in size and capability of spacecraft. For example, in figure 1 note how the transition from spin stabilized to three-axis stabilized spacecraft enabled the continued growth in spacecraft mass, arguably due to the efficiencies gained from new concepts such as the introduction of panel-mounted solar arrays.

Technological advance has been the push for developing large spacecraft, but what has been the pull? For commercial systems, the primary driver is return on investment. If you combine the data from figures 1 and 2, you will discover that for a given increase in spacecraft mass,[8] power increases by a greater fraction (to the power of 1.38). Recognizing that space system cost (including spacecraft and launch cost) increases in proportion to spacecraft mass, there is more "bang for the buck" as mass is increased—with power being the "bang," and mass being the "buck." Using terminology familiar to spacecraft communications service providers, cost per transponder on a spacecraft decreases with larger spacecraft. In order to maximize profit, it only makes sense to build the largest spacecraft possible with existing technology and launch capability. Likewise, for satellites with a given number of transponders, the amortized cost of the spacecraft on a per day basis is reduced as lifetime is increased. This is the incentive to design the already large spacecraft for the longest feasible lifetime.[9]

These cost trends hold for national security space systems as well, mostly regardless of mission type. Instead of maximizing profit, the trend has been to attempt to minimize the cost for a given set of requirements. This approach drives us to maximize the number of capabilities (and hence requirements) per spacecraft. Large multi-payload spacecraft are the result. With requirements established, the systems engineering exercise then is to minimize cost by minimizing size, weight (total spacecraft mass), and power (SWaP) for the design. At the same time, the propellant load is maximized (given launch vehicle constraints) in order to minimize the annual cost of the spacecraft, since it can be amortized over a longer lifetime.

In summary, advancing technology has enabled increases in spacecraft size, power, and lifetime, but these larger, more powerful, and longer living stand-alone spacecraft are the result of users seeking to maximize capability per satellite and minimizing the cost per unit of capability. In a *static* cost-constrained environment, this is a rational economic choice. But we live in an increasingly dynamic world. In this dynamic environment, *uncertainty rules*, and the conventional design paradigm of large spacecraft becomes questionable.

Risk and Opportunity in Today's Large Spacecraft

"Risk is defined as a future event or situation with a realistic (non-zero nor 100 percent) likelihood/probability of occurring and an unfavorable consequence/impact to the successful accomplishment of well-defined goals if it occurs … Opportunity represents the potential for improving value in achieving a goal; risk represents the potential for decreasing the same value."

~ FAA Systems Engineering Manual

Today's very large commercial and military spacecraft are technological marvels. In the planning phase of procurement, the current design paradigm of large, multi-mission, long duration systems makes a great deal of sense in a resource-limited environment. However, while large spacecraft provide incredible capability, they are also unable to respond rapidly to uncertainty throughout the life-cycle of a program.[10] Table 1 displays some of the more notorious uncertain events that can (and have been observed to) occur during a space system's lifetime.[11] The manifestation of uncertainty comes in the form of risk and opportunity, with risk being an unfavorable outcome, and oppor-

tunity being favorable. The examples from table 1 discriminate between these two outcomes which are found on the opposing "tails of the curve."

How are today's space systems designed and managed with risk and opportunity in mind? Let us take a look. The conventional approach to dealing with risk centers around the dual tasks of reducing the probability of occurrence of a failure and containing the failure's impact on the system. We accomplish this through two means: initial design for reliability and the mission assurance process. Enhancements in reliability are effected through redundancy and margins: we typically add double and even triple redundancy to our systems. Mission assurance, which includes quality assurance and risk management, focuses on making sure nothing has "slipped through the cracks." Through design and practice, we attempt to "burn-down" risk so as to maximize mission success. We, however, offer the following observations with respect to current stand-alone (hereafter referred to as "monolithic") spacecraft design:

1. Increased spacecraft size and capability result in increased complexity. This complexity introduces fragility into the system. The manifestations of fragility show up both as programmatically and systematically.
   a. More programmatic complexity increases the probability that some event or small combination of events will result in a major slip in schedule or cause cost growth in the program in excess of its budget. One simple example is a multi-payload spacecraft in which a single instrument becomes a critical path item and causes a significant delay to the entire program.
   b. More design complexity results in more "unknown-unknowns." That is, more possible failure modes are not accounted for and can not be accommodated through design and/or management. In the past decade, how many catastrophic failures were caused by issues *not* previously tracked in the risk management process? Although the data has not been analyzed in detail, the authors believe the answer to be a significant number.
2. With today's monolithic spacecraft, *we place all of our eggs in one basket*. The cost and capability of these space systems are so large that, regardless of the probability of a failure, the impact of that failure is enormous. As the Young committee stated, "one mistake can be mission catastrophic." Catastrophic indeed—one failure could result in the loss of hundreds of millions of dollars and years of needed warfighting capability.

Given these observations, we see that the risk inherent in our space systems is very high. Now appearing on program risk charts with more prominence is the ever-increasing threat of attack on our space systems. Just as reliability and quality are used to reduce the probability of component failure, survivability must now be emphasized as part of mission assurance to reduce the probability of the occurrence of a variety of possible hostile and high-impact events. Once again we face the "one strike and you're out" scenario. What we desire to achieve, through reliability, survivability, and limited fragility, is robustness—the ability to retain the original capabilities intended in the system, even in the face of uncertain, environmentally-driven phenomena.

But what of our opportunities? Certainly, our space systems provide great utility when they are successful. But opportunity, the inverse of risk, is really a measure of the likelihood of providing additional value in the face of uncertainty. Table 1 highlighted several opportunities, many of them dealing with improved technologies which follow Moore's Law. Not only can we *not* keep up with technological advances, today's large spacecraft are already notoriously behind the "technology curve" at launch, by which time they usually contain components at least a decade old. By the end of their on-orbit lives, they are, relatively speaking, technological dinosaurs.

Really, what we are talking about here is incorporating flexibility—the ability to change or modify a system at any time during its life-cycle. Recent experience has proven the flexibility offered by software-centric reprogrammable systems to be significant. With regard to the ability to change or modify hardware, however, our large space systems do not have much flexibility—and for good reason. Flexibility is not an inherent part of a system—it must be designed into it. Adding flexibility comes at some cost, while doing little to ensure basic requirements are met. When focusing on meeting the requirements at hand and minimizing the risks, opportunity rarely receives a thought—par-

LIFECYCLE UNCERTAINTIES			
Perturbation	*Definition*	*Example(s)*	*Risk/Opportunity*
Development Problem	A problem arising during the development phase leading to a workstream delay or budget overrun.	▫ Failure to mature a technology ▫ Payload damaged during test	▫ Risk ▫ Risk
Funding Fluctuation	Volatility (usually, but not necessarily, a reduction) in the available budget	▫ Funding cut ▫ Funding increase	▫ Risk ▫ Opportunity
Requirements Change	A change in program objectives subsequent to their initial definition and commencement of development	▫ New threat identified during design ▫ New stakeholder enters program	▫ Opportunity ▫ Opportunity
Launch Failure	Failure of launch vehicle payload to reach desired orbit	▫ Explosion of launch vehicle ▫ Failure of upper stage rocket	▫ Risk ▫ Risk
On-orbit Failure	Component failure on orbit due to internal or external event	▫ Processor failure ▫ Micrometeorite impact	▫ Risk ▫ Risk
Demand Increase	Demand for mission service exceeds original expectations during development	▫ Increased bandwidth needed in theater ▫ New TV technology requires additional bandwidth	▫ Opportunity ▫ Opportunity
Obsolescence	Emergence of new technologies favor newly-designed components over existing assets	▫ Emergence of novel antenna or sensor technology ▫ Moore's Law	▫ Opportunity ▫ Opportunity

Table 1. Spacecraft Life-cycle Uncertain Events.

ticularly since it comes at a cost. In a cost-centric acquisition paradigm, the systems engineering exercise will always focus on minimizing risk.[12]

Our conclusion is that today's space system design paradigm yields large and complex systems which possess great risk, but limited opportunity. One thought is that smaller systems could prove to be more manageable, less complex, and more able to quickly react to uncertain events, while the impact of their loss could be less severe. Unfortunately, while smaller systems may provide reduced risk and increased opportunity, they cannot match the performance demanded of larger spacecraft. We cannot return to the past and build small spacecraft for all of our national security needs. Or can we?

A New Trend: Distributed and Fractionated Systems

"Big platforms might be built by sending up components, 184 pounds at a time, for example. Eventually, this way, a telescopic sky station might be established."[13]

~ Robert Plumb, *New York Times*, October 1957

A mere four days after the launch of Sputnik, the *New York Times* article quoted here predicted great things to come in the conquest of space, including a look at how larger, more capable space systems could be built. Obviously, at the time, it appeared a simple limitation and the only way to get larger, more capable systems into orbit was a building block approach which physically linked components together in space. As we have described, this became unnecessary as technology enabled larger, more capable, monolithic satellites to be built and launched. But, let us revisit the architectural approach offered in 1957. First we need to consider how modern technology can make this approach more tractable. Then we can address how it can significantly alter the high risks and low opportunities presented by large and complex monolithic systems.

Earlier we charted the evolutionary development of multi-payload spacecraft. One can easily imagine the distribution of these multiple payloads onto smaller individual spacecraft. Such approaches have been discussed before, and in many ways represent the old way of doing business. But now let us take this idea one step further, a step that at first may sound like something out of science fiction. Is it possible to decompose a spacecraft, payload by payload and subsystem by subsystem, into physically separate functional elements—individual spacecraft modules? Then can we create a "virtual satellite" by wirelessly networking these elements together? To be more specific, consider that today's spacecraft are essentially systems of payloads and bus support subsystems. The latter include computers, telemetry tracking, and command (TT&C) transceivers, mission data downlinks, navigation sensors (e.g., star trackers, global positioning satellite [GPS] receivers), power sources, propulsion equipment, and a supporting structure. The payloads, computers, TT&C, and mission data downlinks are "glued" together by data first and structure second. In today's world of Wi-Fi hotspots, we recognize that data need not be transported over a cable, but rather can flow through the ether. Similarly, it is not difficult to imagine a clustered space system composed of wirelessly networked modules orbiting just kilometers apart. Some modules could contain specific payloads, while others act as the computing nodes, the TT&C nodes, and the mission data downlink nodes. This process of physically decomposing a spacecraft into a distributed network of wirelessly connected modules is what we call "fractionation."

What about further fractionation? Could one fractionate the power subsystem? Yes! Imagine a central solar power hub collecting sunlight, converting it to electricity, and then "beaming" that power via laser, millimeter radio-wave, or specially tuned induction to other elements in the cluster. How about navigation sensors? Since they determine absolute position and inertial attitude, fractionation of these subsystems sounds daunting. However, if we think of a module with a GPS receiver and several relative navigation sensors (already developed or in development) onboard, this module can determine the relative distances to other modules and their relative attitudes. In essence, this module becomes the navigation element for the larger cluster. Finally, let us consider the fractionation of the propulsion subsystem. Imagine an infrastructure, in which a "space tug" accomplishes a rendezvous and docks with a spacecraft module, reorients and/or repositions it, and then moves on. An even newer concept to propulsion fractionation at first appears to be a ridiculous notion—the transmission of forces and torques between neighboring spacecraft with no physical connections. But, researchers at the Massachusetts Institute of Technology have demonstrated "electro-magnetic formation flight" (EMFF) in the laboratory.[14] With EMFF, magnetic fields are created around modules using specifically designed wire bundles. By controlling the direction (of the north and south poles) and strength of the magnetic field, modules can be attracted, repulsed, and even rotated relative to one another. Using either the tug or EMFF approach, it may be possible for a centralized propulsion module to move an entire cluster "glued" together by docking mechanisms or magnetic forces.

At this stage, it is important to distinguish the concept of fractionation from other approaches to distributed spacecraft. For example, fractionation is not necessarily a formation flying system. Such systems, like those designed for the TechSat 21 program, consist of a multitude of similar spacecraft flying in a very tightly-controlled formation for the purpose of creating a larger sensing aperture. Certainly this is an example of fractionation, but one we call "homogeneous" since the same spacecraft are replicated to produce the formation. The larger superset of fractionation we are describing in detail here can be homogeneous (all modules similar), heterogeneous (all modules different), or a hybrid mix of the two. Fractionation can involve tightly controlled (relative positions down to the centimeter or millimeter) formation flight. However, for wider applications, fractionation also can be a loosely controlled (relative positions down to the meter) cluster with varying relative distances on the order of tens, hundreds, or thousands of meters. Such relative distances are required only to close communications links with minimally acceptable latencies. More recently, novel architectural concepts such as the Space-Based Group have been proposed in which one module acts as the central mission data

downlink hub for a cluster of other spacecraft.[15] Again, this is a subset of fractionation.

At a higher level, the fractionation we are describing is a more general concept, which allows distribution not only of data downlink resources, but also other infrastructure resources such as computing, navigation, and power. With this networked approach, many degrees of freedom are now created in the design process allowing the distribution and diversification of payloads and infrastructure (i.e., communications to the ground, processing, etc.) in a way that allows a stakeholder to trade cost, risk, and performance. Note that this means *how* to fractionate is now a choice. For instance, now one can choose to launch all modules in a cluster at once, on separate smaller vehicles, or a combination thereof. All of one resource (e.g., mission data processing) can reside on one module, be spread evenly across all modules, or something in between. Some modules, such as those that provide computing resources, may be very small—in the picosat or nanosat realm. Alternatively, some modules hosting payloads may still require large structures (e.g., telescopes). In this case, the choice may be made to launch what looks like a conventional monolith, but with a wireless networking capability that allows infrastructural upgrades after launch. Finally, over time, a "bus in the sky" of infrastructure can develop, which results in a space architecture that alleviates a great deal of burden to the service provider and stakeholder: an in-orbit "plug and play architecture" could evolve, with the minor exception that there are no plugs!

Assuming fractionation is possible, why would one want to build a fractionated spacecraft? At first glance, it appears to be a more costly endeavor resulting from the overhead brought about by the decomposition process. For example, assuming the propulsion subsystem is not fractionated out, each module must carry some propulsion and structure. This implies a larger aggregate mass, and correspondingly more cost. The answer is two-fold. First, recognize that a cursory analysis misses many possible offsets to cost which this new architecture may provide. Second, for an equitable comparison between the monolith and a fractionated system, we must deviate from our standard static cost analysis and consider the impact of uncertainty on each approach. When considering the changes in risk and opportunity offered by a fractionated architecture, as well as possible enhancements in capabilities, the new design approach warrants serious attention.

Cost, Risk, and Opportunity with Fractionated Space Systems

"So the central lesson from decision-making … is the following: it is the exposure (or payoff) that creates the complexity—and the opportunities and dangers—not so much the knowledge … In some situations, you can be extremely wrong and be fine, in others you can be slightly wrong and explode."[16]

~ Nassim Nicholas Taleb

Let us first examine the cost proposition for a fractionated space system. From a SWaP-only argument, it may appear that fractionation is unwarranted. But consider the following:

1. The modular architecture offered by fractionation benefits from production learning effects afforded by an "assembly-line" approach to building modules. Some resource modules could be similar across a number of missions and be common to a variety of clusters. The effect would be to drive module costs down.
2. The decomposition of mission and payload into separate modules significantly reduces systems engineering costs. This effect is due to the decoupling of requirements throughout the system. By physically separating functional elements, the transmission of thermal and mechanical phenomena is eliminated while electromagnetic interactions are severely reduced. For example, the precision pointing requirements for a given payload flow only to its host module. All other modules in the system maintain only the pointing requirements demanded by the resources they host.
3. The modular nature of a fractionated system leads to a supplier infrastructure which develops modules based on their expertise. Also, modules are built with lifetimes and reliabilities tailored to and suited for their tasks. Both of these attributes, influenced by something akin to the economic law of comparative advantage,[17] lead to cost reductions throughout the system.

The cost impacts above are ones that are rather predictive—based on well-controlled, known, and therefore well-estimated processes and tasks. But what of the impacts on cost due to uncertain and unpredictable events? That is, how does a fractionated approach compare to a monolithic one in risk? The effect fractionation has on risk is one of the key motivations behind considering it. Through diversification of assets, fractionation naturally offers inherent robustness and hence the potential to significantly reduce risk throughout a space system's life-cycle. Also, the fractionation process significantly increases flexibility, mainly because smaller modules can address time-critical needs in the system. Through flexibility, more opportunity is enabled. The overall impact of this increase in robustness and flexibility—or alternatively, a decrease in risk and increase in opportunity—is to significantly reduce both the known and unknown costs while increasing the predictable value of a space system.

To be more specific with regards to these points, let us re-examine our three initial observations of the causes of high risk in monolithic spacecraft in order to determine how a fractionated architecture can alter its risk profile.

1. Decomposition of a space system into smaller modules implies that the development delay of a given component on one module does not impact the entire system schedule. Every other module continues on its schedule and is launched independently to incrementally add capability to the system.
2. With a fractionated space system, all eggs need not be placed in one basket. For instance, a decision can be made to distribute the launch of a system across several launch vehicles. If one launch fails, the entire system is not lost. In aggregate, we have shown that the maximum number of launches required to reach 3σ or 6σ mission assurance

confidence can be significantly reduced.[18] Another impact of a fractionated architecture is that on-orbit component failures need not be catastrophic. With a clustered system of networked modules, the failure of any one smaller module can be corrected by building and rapidly launching a replacement module. With a monolith, the only solution is to wait for another monolith to be built and launched—a more costly and time-consuming endeavor. In fact, it is possible to develop a fractionated architecture in which support functions are replicated throughout the entire cluster, or can even be shared *across* clusters. In these scenarios, the response to a failure in a given support function can be nearly instantaneous. Note that this approach means redundancy can be incorporated into the system by using single string modules, as opposed to today's conventional double or triple redundancy approach (which adds mass and complexity).

3. As previously described, fractionation of functionality into separate modules isolates what were once physically connected subsystems or payloads. Eliminating mechanical interactions, and limiting electromagnetic ones, reduces the number of not only known, but also unknown failure scenarios. It also drastically reduces the upfront integration effort required to make systems with very different demands work together.

These arguments can be visualized using typical risk management tools. Figure 4 shows a standard risk management chart, where the probability of occurrence of a risk event is charted against its consequence (impact) on the overall system. When we previously described the "one strike and you're out" character of very large monolithic systems, we were saying that a significant number of failure scenarios, regardless of the probability of their occurrence, have large impacts. Thus, despite the forecasts of risk managers, those potentially catastrophic risks associated with large monoliths are clustered on the right, in the predominantly high risk (red zone), section of the standard risk chart. We argue that fractionated systems, by the very nature of their distributed but networked operation, tend to have risks—likely or unlikely, known or unknown—closer to the left side of a risk chart in an area where the impact on the entire system is reduced. The ability to reduce the impact of risk events by simply changing the architectural paradigm, rather than the number and nature of redundant systems, is one of the strongest benefits of fractionation.

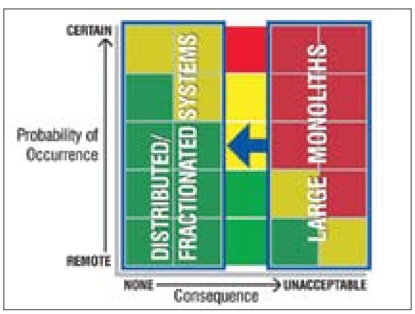


Figure 4. Risk Chart Comparing Monolithic and Fractionated Systems.

Since this qualitative argument for fractionation's effect on risk reduction holds for the effects of on-orbit attack as well as component failure, we conclude that a fractionated architecture provides inherent space protection as well. As with an organic component failure, a successful attack on one element of a cluster does not necessarily result in complete and catastrophic failure of the system. Redistribution of required resources within or across clusters, or rapid launch of new replacement modules is possible. The concept of defensive maneuver is also made possible by the physically distributed nature of fractionation. Cluster size, geometry, and configuration can all be changed in order to minimize the probability of direct or indirect (by debris) hostile impact.

Opportunity is enabled by the flexibility inherent in a fractionated architecture. Adapting to new mission requirements, evolving to new technologies, and scaling to increased demands can all be accomplished with the insertion of smaller new modules containing the requisite capability into the already orbiting system. For instance, suppose a new mission processor is desired for an orbiting space system. With the fractionated approach, a relatively small spacecraft containing a new high performance processor can be rapidly launched, inserted into the orbiting network, and thus improve system performance. Also note the significance of being able to scale to ever-greater capability: Figure 1, previously discussed, showed the trend of ever increasing spacecraft size, driven by demand for ever-greater capability. This trend can-not continue forever: within the next one to two decades, if the trend continues, we will reach the lift limitations of our domestic large lift vehicles. So, fractionation can provide the opportunity to get desired capability to orbit, regardless of launch vehicle limitations.

To visualize the opportunity gap between monolithic and fractionated architectures, consider figure 5. This is a risk chart adapted for use in identifying critical system opportunities. As with the previous risk chart, the probability of occurrence of an opportunity event is charted against its overall consequence. The difference from the risk chart is that when both measures are high, we have a favorable green zone result identifying an opportunity event that can be captured to yield appreciable results. Our contention is that the inflexible monolithic design methods confine large monoliths to a region on the bottom of this chart where the likelihood of taking advantage of an unforeseen future event is remote. Contrast this to fractionated systems in which the probability that opportunities can be exercised is significantly increased: because of the smaller size of discrete modules and the capability to utilize existing infrastructure, the architecture inherently provides greater flexibility to scale, evolve, and adapt to unforeseen events.

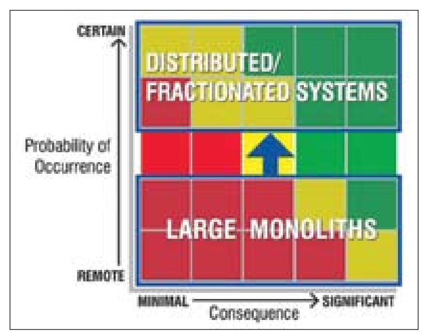


Figure 5. Opportunity Chart Comparing Monolithic and Fractionated Systems.

Of course, one risk for fractionated architectures still remains—the concept exists only on Power Point charts today. However, DARPA is taking on the challenge of proving the viability of this new concept by attempting to demonstrate it

on-orbit. Recently, a new program called System F6 began the process of taking technical excuse off the table. It seeks to develop the technologies necessary to create fractionated satellite systems and integrate them into our future national security space architecture.

System F6 Program

DARPA's System F6 program, started in February 2008, will attempt to develop and integrate the technologies necessary to demonstrate the feasibility of a fractionated spacecraft.[19] This program is named the Future, Flexible, Fast, Fractionated, Free-Flying Spacecraft united by Information eXchange—or simply System F6. Its goal is to develop the core technologies that enable fractionation as well as a suite of system engineering tools necessary to help determine the most cost effective designs.

As depicted in figure 6, F6 is defined by six enabling concepts, each of which must be adequately addressed if fractionation is to become a reality.

- Robust, self-forming *networks*: Every device on every spacecraft module in the cluster should act as a uniquely addressable node on a network. Ideally, the network autonomously accepts new spacecraft modules, reconfigures the network to route around failed nodes, and adapts to unanticipated events or the emergence of new capabilities.
- Secure, reliable, and interference-resistant *wireless communication*: The F6 program is exploring the adaptation of a variety of terrestrial wireless communications standards, as well as the development of entirely new ones, to meet the stringent information assurance requirements of national security space systems.
- Scalable, adaptable, and fault tolerant *distributed computing*: A distributed computing layer, operating just above the network layer, enables the sharing of resources—for example, a data processor, a storage device, a communications link, or a sensor—across the network. Resources can be added to the network and utilized by any distributed application. If a processor on board one spacecraft module fails, that module will be able to use a processor located anywhere else on the network—even on network nodes located on other modules, or on the ground.
- Efficient, available, and non-interfering *wireless power transfer*: Beaming power between modules may provide enhanced capabilities for certain space systems.
- Autonomous, safe, and self-defending *cluster navigation*: Spacecraft clusters require autonomous cluster management, stationkeeping schemes, collision avoidance strategies, and survivability features such as "scattering" behaviors in the presence of external threats.
- *Econometrics*, that is, the use of mathematical tools from economics to make rational system engineering trade decisions. We have discussed how fractionated systems promise to reduce risk and increase opportunity for space systems, but the key question will be: how much should one be willing to pay for this? Using a variety of relatively new analysis tools, we hope to quantify the financial impact of risk reductions and opportunity increases. These tools, once integrated in the systems engineering process, will provide decision makers with the appropriate knowledge they need to trade capability, cost, risk, and opportunity. We plan to detail this approach in a subsequent *High Frontier* article.

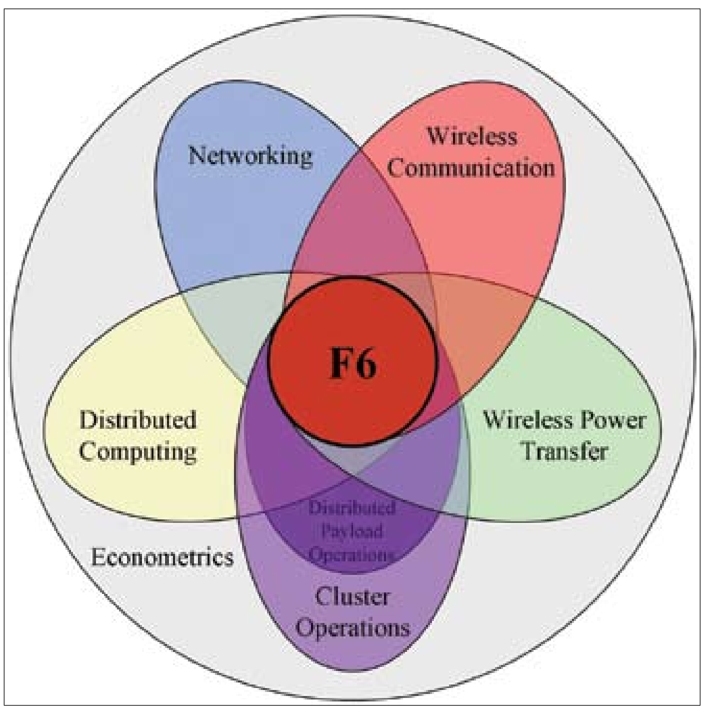


Figure 6. System F6 Enabling Concepts.

It is planned that within four years of the program start, System F6 will be testing fractionation technologies and concepts with a demonstration in orbit of a fractionated space system, which will replicate important national space security missions.

Conclusion

Over the last 50 years our space systems have become incredibly capable and are a key to our national economy and defense. With capability, however, comes risk and limited opportunity—mainly due to the large size and associated complexity of our most costly spacecraft. Fractionation is an approach in which modern technologies are used to decompose large systems into smaller physical elements. This process provides for a diversification of assets and resources in an effort to reduce risk. It also enables the rapid addition or replacement of components, thereby providing great opportunities throughout a space system's life-cycle. DARPA has initiated a program, called System F6, which aims to demonstrate the feasibility of this approach. If successful, our future national space architecture could see dramatic change, as it evolves into a system of systems—a highly integrated space network, where computer processing, downlink, and other resources are available for use in orbit much like an electric outlet or WiFi hotspot are available in your home today.

Notes:

[1] Thomas Young, Chairman of the Mars Program Independent Assessment Team before the House Science Committee, tesimony; Mars Program Independent Assessment Team Summary Report, 14 March 2000, 3, ftp://ftp.hq.nasa.gov/pub/pao/reports/2000/2000_mpiat_summary.pdf.

[2] Moore's Law refers to the historical trend indicating that the number of transistors which can be placed on an integrated circuit doubles every 24 months. Processing speed, memory capacity, and other measures of computing capability tend to increase at correspondingly exponential rates.

[3] The Defense Advanced Research Projects Agency (DARPA) is an agency of the Department of Defense charged with developing technologies which are considered too high risk for other government research and development agencies, but which also present opportunities for extremely high rewards. Former DARPA programs include development of the initial protocols and architecture for the internet as well as the radar absorbing material and novel design for stealth aircraft.

[4] "Universal Shift," *Janes Defense Weekly* 44, no. 41, 10 October 2007.

[5] Although small, Explorer 1 proved capable: it carried a science package that is credited with discovery of a belt of charged radiation, now named after the Principle Investigator, Dr. Charles Van Allen.

[6] P. R. Anderson and L. Bartamian, "Growth Trends in Communications Satellites and the Impact on Satellite System Architecture," 26th International Communications Satellite Systems Conference, 10-12 June 1998, (AIAA 2008-5440). Figures 1, 2, and 3 are incorporated in this article with the permission of the authors.

[7] These growth trends continue, for example as the commercial ICO G1 spacecraft launched in April 2008 had a beginning of life mass of 6,634 kg and power of 16KW. Reference "Lockheed Martin Successfully Launches ICO G1 Mobile Interactive Media Spacecraft," *PR Newswire*, 14 April 2008.

[8] Launch cost increase roughly linearly with spacecraft mass, while spacecraft cost increase exponentially with spacecraft mass. Reference, for example, Wiley Larson and James Wertz, eds., *Space Mission Analysis and Design*, 3rd ed., (Space Technology Library, 2006).

[9] Joseph Saleh, "Flawed metrics: satellite cost per transponder and cost per operational day," IEEE Transactions on Aerospace and Electronic Systems, 2006. This paper points out that the metrics discussed here are misleading unless one considers value, not just cost, in the face of uncertainty.

[10] Owen Brown and Paul Eremenko, "Fractionated Space Architectures: A Vision for Responsive Space," 4th AIAA Responsive Space Conference, Los Angeles, CA, 2006 (AIAA-RS4-2006-1002).

[11] Owen Brown and Paul Eremenko, "Application of Value-Centric Design to Space Architectures: The Case of Fractionated Spacecraft," AIAA Space 2008 Symposium, September 2008 (AIAA 2008-7869).

[12] The Space and Mission Systems Center (SMC) Systems Engineering Manual from cover to cover refers to the words "risk" 408 times, and "opportunity" 8 times.

[13] Robert Plumb, "New Space Conquests Can Now Be Foreseen," *New York Times*, 6 October 1957.

[14] Edmund Kong, Daniel Kwon, et al., "Electromagnetic Formation Flight for Multisatellite Arrays," *Journal of Spacecraft and Rockets* 41, no. 4, 2004, 659-666.

[15] G. Payton, speech by Deputy Undersecretary of the Air Force – Space to AIAA Astrodynamics and AAS Space Flight Mechanics Technical Committees, 2008 Astrodynamics Specialist Conference, 18 August 2008.

[16] Nassim Nicholas Taleb, "The Fourth Quadrant: A Map of the Limit of Statistics," original essay available at http://www.edge.org/3rd_culture/taleb08/taleb08_index.html. Taleb is also the author of "The Black Swan: The Impact of the Highly Improbable" (Random House) a recent best selling book which discusses the role of seemingly improbable but potentially catastrophic or serendipitous events in our daily lives.

[17] The law of comparative advantage states that economic efficiencies are gained in world trade by allowing products to be produced by those countries which can manufacture and deliver them the most cheaply.

[18] Owen Brown, "Reducing Risk Through a Modular Architecture," Aerospace Corp Risk Management Symposium, 2005.

[19] "DARPA Awards Contracts for Fractionated Spacecraft Program," 26 February 2008, http://www.darpa.mil/body/news/2008/F6.pdf.

Mr. Naresh Shah (BS, Astronautical Engineering and Mathematical Sciences, US Air Force Academy; MS, Aeronautics and Astronautics, Massachusetts Institute of Technology; MA, Organizational Management, George Washington University) is an associate with Booz Allen Hamilton's Global Defense – Science and Technology practice and serves as the program lead for Defense Advanced Research Projects Agency's (DARPA's) System F6 program. He is responsible for ensuring the successful achievement of program milestones and goals by the four program performers, as well as coordinating the activities of the 35-person government team ensuring verification and validation of all program objectives. He also provides professional technical services in the field of orbital mechanics and space systems engineering. In his capacity as a consultant, Mr. Shah provides program management, technology analysis and decision support services to several DoD agencies.

Mr. Shah is a former US Air Force Major, having obtained his commission as a distinguished graduate from the US Air Force Academy in 1995. He started his military career as a Draper Fellow with the Charles Stark Draper Laboratory, where he conducted research into the automated control of satellite constellations. As an Air Force intern, he worked at the National Reconnaissance Office as a deputy program manager for an advanced technology demonstrator program Mr. Shah has flown operational assignments at both stateside and overseas locations in the KC-135. He separated from the Air Force in 2002 as a senior pilot with more than 2,300 flying hours and several combat deployments.

Dr. Owen C. Brown (BS, Engineering Science, Loyola College Baltimore; MS and PhD, Aeronautical and Astronautical Engineering, Stanford University) is a program manager in the Tactical Technology Office (TTO) at the Defense Advanced Research Projects Agency (DARPA) in Arlington, Virgina. He is responsible for conceiving, developing, and managing radically innovative space systems for national security. In this role since 2003, he was the program manager for the design, integration, test, launch, and demonstration of the joint DARPA, Air Force, and Navy Microsatellite Technology Experiment. He now manages the System F6 program which he conceived, as well as several smaller space system technology development projects. Dr. Brown served on active duty in the US Navy from 1984 to 1990 as a nuclear trained submarine officer; he was assigned to the fast attack submarines USS Flying Fish (SSN 673) and USS Sturgeon (SSN 637) in a variety of engineering and operations positions. At Stanford he acted as a teaching assistant for graduate propulsion courses, and was a research assistant at the NASA Ames Research Center. He was employed at Space Systems/Loral in Palo Alto, California for seven years as a spacecraft reliability, propulsion, and systems engineer. In these roles he was responsible for various aspects of the design, test, integration, and launch of a variety of large geosynchronous satellites. From 2001 to 2003 he served as a technical consultant to DARPA/TTO for space programs. He led technical efforts for the Rapid Access Small Cargo Affordable Launch program in this position. Dr. Brown recently transitioned to a retired status in the Navy Reserve with the rank of commander after 20 years of combined active and reserve duty. He is the author of many technical papers, and has acted as a distinguished lecturer for the American Institute of Aeronautics and Astronautics on space history and aerospace topics.

Space Situational Awareness Architecture Assessment

Mr. Phillip D. Bowen
Director Surveillance and Intelligence Systems
Lockheed Martin Space Systems Company
Denver, Colorado

Mr. Clifton Spier
Director, Strategic C4ISR Capabilities Unit
Lockheed Martin Information Systems and Global Services
Colorado Springs, Colorado

The United States holds an asymmetric advantage in space that is essential to supporting our national security as well as civil and commercial objectives. The US National Security Space strategy supports a growing range of missions across the intelligence community and Department of Defense (DoD) including intelligence, surveillance, and reconnaissance (ISR), precision navigation, secure communications, missile warning, and environmental monitoring.

Many countries are rapidly moving forward with space capabilities challenging advantages the US currently enjoys. These nations are pursuing the space frontier to gain the status associated with being a space faring nation, and ultimately to further their economic development and enhance their military power. The pace of advancement in space systems is accelerating and maturing to be on par with the US potentially within the next 10 years. Nations or non-state players will have the means necessary to threaten US space systems and consequently national security. As stated in Executive Order 12333, "Timely, accurate, and insightful information about the activities, capabilities, plans, and intentions of foreign powers, organizations, and persons, and their agents, is essential to the national security of the United States." The capabilities provided by our space systems are fundamental to enabling the Executive Order as well as our warfighter operations and must be protected in a similar manner as the military's ground, maritime, and air operations.

The US has the world's most advanced space surveillance capabilities, but does not have the persistent, predictive, real-time space situational awareness (SSA) necessary to advance and protect US interests in the future. There is a critical need to protect America's space assets, and the protection mission must emphasize an all encompassing approach to SSA, in order to assure freedom of access to space. SSA has become much more than the historical metric track-object cataloging functions performed by the existing space surveillance network (SSN). SSA requires not only the ability to locate objects in space to maintain the catalog, but must also include a cradle to grave function from moment of launch for all orbiting objects to determine their capabilities, intent and threat potential. The impending micro/nano-satellite era highlights the need for SSA systems to have greater sensitivity and capability for near real time surveillance and characterization of smaller objects to provide information rapidly to military and civil decision-makers.

The Lockheed Martin Corporation was requested, because of the breadth of its corporate-wide capabilities, to provide a comprehensive SSA architecture perspective for consideration by senior DoD officials. The request was to address the mission to help the government define an approach for an objective system SSA program plan. Our approach leverages the extensive experience of our different business areas including: Lockheed Martin Space Systems, which has provided the US the majority of national space systems over many decades; Lockheed Martin Integrated Systems and Global Services, which provides information systems and ground segments for national and DoD systems; and Lockheed Martin Maritime Sensors and Systems which provides the US government with a number of strategic and tactical radar systems.

This article highlights our SSA architectural approach. It begins with an assessment of government provided mission threads that along with threat assessments, provided a basis for assessing the capabilities of the current and near term SSN. The threads were analyzed to define SSA system attributes that provided a basis for assessing current abilities to detect and attribute a threat, and also define needed defensive protection requirements. These assessments led to a determination of SSA knowledge gaps that provided a basis for identifying current and projected mission needs, finally leading to candidate solutions capable of satisfying the future SSA mission.

Architecture Analysis and Evaluation

SSA objectives have been defined by performing surveillance, reconnaissance, intelligence and environment awareness missions. The effectiveness of different SSA architectures has been measured against these objectives. Instead of attempting to address the entire solution set of SSA, Lockheed Martin chose to make some up front assumptions to focus on near term SSA needs. Typically with any architecture, the last 10-20 percent of capability ends up driving the architecture to a higher complexity and cost. We chose to focus our architecture assessment on space protection, driving to understand threats and their associated solutions from a military utility perspective. This focus quickly identified gaps and possible solutions that could then be applied back to overall SSA with an '80 percent' answer. A core definition in the evaluation tied the effectiveness back to military utility. Was the solution able to detect a threat, attribute a threat action, or could it actually enable a defensive response? A standard systems engineering process was used to understand the needs, evaluate them against potential

solution sets, and then iterate on the process. In the end, we tested our results with various government and military agencies, making sure the assumptions and the logic of the conclusions were accurate.

Figure 1 shows the engineering evaluation process from a threat based, military utility perspective. SSA objectives were shaped by defined mission threads, and key attributes were defined and evaluated against the current state to identify gaps in SSA today. Individual candidate solutions (both information systems and sensors) were identified and evaluated for their effectiveness (detection, attribution, enabling of defensive action) for the mission threads.

Lockheed Martin's assessment started with a prioritized set of mission threads, or technical performance measures, from the Air Force Space and Missile Center's architecture group. These mission threads are divided into two functional areas:

1. Space protection event threads, described best as the identification of separate one time event threats to spacecraft at different orbit regimes.
2. Deliberative planning threads, best described as 'routine user needs' space surveillance data for flight safety (conjunction analysis, overflight warning, etc.).

These threads represented a very comprehensive base from which to evaluate a threat based SSA architecture.

Mission threads were analyzed to establish key system attributes as measurements to quantify the effectiveness of an architecture. These are defined as sensitivity, capacity, coverage, latency, resolution, data quality, data accessibility, system timeliness, predictive/planning capability, and adaptive/flexibility. This total set represented a comprehensive look at effectiveness. Some of the attributes are a direct measure or quantifiable value of a system, others focus on how well a system can integrate and act on information. Criteria were developed for each one of these as they were mapped back into the mission threads. All of the attributes had different definitions and effectiveness criteria for a particular mission thread, but not all attributes were applicable to each one. The attributes were then weighted as to their importance to solve the specific mission thread. Schedule and cost were used as programmatic measurements of a solution's affordability to the over-all SSA architecture.

A subjective analysis at this point focused the assessment on the low-Earth orbit (LEO) and geosynchronous-Earth orbit (GEO) orbit regimes only. These orbit regimes contain the most assets to be protected. We also noticed the implementation of candidate solutions tended to group around timeframes of 18 months, 3-5 years, and 5-7 years. Our initial assessment evaluated the architecture at these discrete points in the future, rather than a continuum of different solutions over time. Both assumptions streamlined the process and focused the evaluation squarely on a near term, threat based architecture.

Evaluation of today's SSA architecture was used to expose the gaps in current capability, using the military utility effectiveness of detection, attribution or ability to enable defensive actions. The evaluation and subsequent gaps were identified for each individual mission thread. Using this threat based focus, we quantified high priority SSA needs and started to match with potential solutions. From the mission threads and mapping of key attributes, the high priority needs of an effective architecture were identified on a mission thread basis. These needs were defined in terms of quantifiable attributes (examples: timeliness, quantity, resolution, etc.) and were established for the mission threads at both the LEO and GEO orbit regimes.

Lockheed Martin has had a role in SSA throughout the years by providing over-arching systems, information systems integration, and sensors (both space and ground). We have leveraged this experience to create the 'current state' architecture evaluation. We then turned our attention to identify ongoing programs and other potential initiatives that compared favorably to the value assessment identified by the gaps. These formed the candidate solutions and are a mixture of contracted activities and proposed or projected capabilities—whether a Lockheed Martin product or not. The candidate solutions were grouped into information systems solutions (integration of sensor information) and sensor solutions (both space and ground).

The candidate solutions were evaluated against the attributes and the threads as an architecture for effectiveness at the 18 month, 3-5 year, and 5-7 year time frames. Our evaluation used mission thread closure as

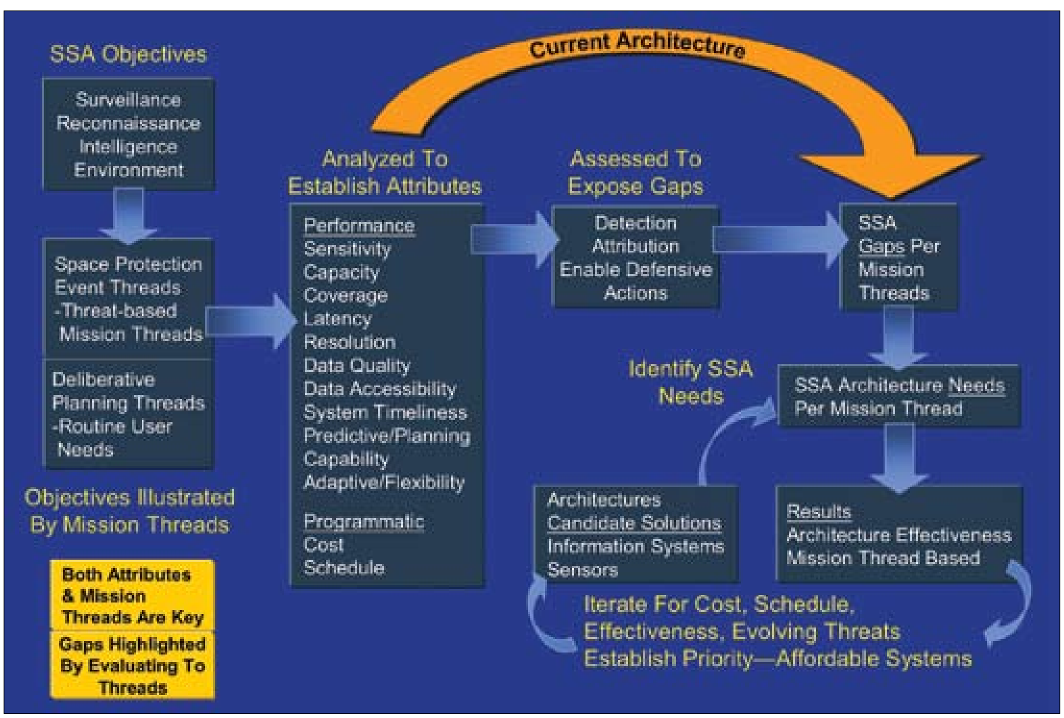


Figure 1. Space Situational Awareness Architecture Evaluation Flow.

the key criteria of effectiveness—detection, attribution, and enabling of a defensive action. The mission thread was considered fully mature when the last step, enabling defensive action, was satisfied. The results were then compared back to today's architecture to analyze and make initial recommendations. Once the framework was established, Lockheed Martin used an internal value model to iterate back on the architecture solutions. This allowed a parametric insight into the individual solutions to view contributing effectiveness versus cost, risk, and schedule. Summation of the results were briefed and tested with several SSA government agencies to validate the conclusions.

Not one information system or sensor solution can satisfy the architecture needs, even for a threat based, mission driven architecture. Information systems provide the earliest pay-off for any architecture, in that the solutions can start to better utilize existing sensor data almost immediately. It became clear that both information systems and sensors (existing and new) needed to be integrated together as a system in a layered architecture, with timely handover and access from one system to another. Geosynchronous space has the most critical need for SSA solutions—a conclusion that was illuminated by the focus on mission threads, threat based scenarios, and operational military utility. Finally, in an environment where not all solutions and good ideas can be funded—missions with the highest threats and vulnerabilities need to be prioritized.

Information Systems and Infrastructure

We identified six information system element solutions: (1) a modern infrastructure to provide the means of discovering and exploiting data and services from a variety of national, DoD and unclassified systems; (2) appropriately integrating the resulting data into fused battlespace awareness pictures, from analysts to the commander, providing decision quality information though user defined operating pictures (UDOPs); (3) continuing to develop a high precision space catalog; (4) developing a space situation monitoring and assessment capability of the entire battlespace—the situation model; (5) providing an effects-based planning capability; and, (6) for future space systems, developing a multi-mission space operations center. These elements are depicted in figure 2 which shows a functional information systems view.

At the foundation of our next operational space system is a modern services oriented architecture (SOA) infrastructure to provide the means of discovering and exploiting data and services from a variety of national and DoD systems. To avoid the pitfalls of the past and to enable agility and flexibility, the space information solutions infrastructure must be standards based, not products based. This allows flexibility in choosing and evolving products to meet the growing maturity and capabilities of commercial off-the-shelf/government off-the-shelf and commercial products and services. There are a few mature SOA implementations in place today and a few being developed. While this article does not address the merits of choosing one or another, timeliness of action dictates choosing an existing SOA and continuing to modernize it via 'technology refreshing.'

It is well known that there is a barrier between intelligence information and surveillance information. A second part of the infrastructure is solving moving data across the multiple security domains, in particular among Non-Secure Internet Protocol Router Network (NIPRNet), SECRET Internet Protocol Router Network (SIPRNet), and Joint Worldwide Intelligence Communications System (JWICS). Until there is a certified enterprise level multi-level security (MLS) cross-domain solution available, we recommend MSL solutions to allow for data to flow from lower security classification levels to higher security classification levels. This enables an operational setting such that surveillance data may be fused with intelligence information to provide a necessary condition for awareness completeness. Instantiating separate SOAs at the NIPRNet, SIPRNet, and JWICS levels with guards, provides the timeliest solution of getting unclassified, secret, and top secret/sensitive compartmented information data into one security domain so that this data can be associated and exploited as outlined in the following paragraph.

The second element of the space information system element solution is appropriately integrating existing data (ISR,

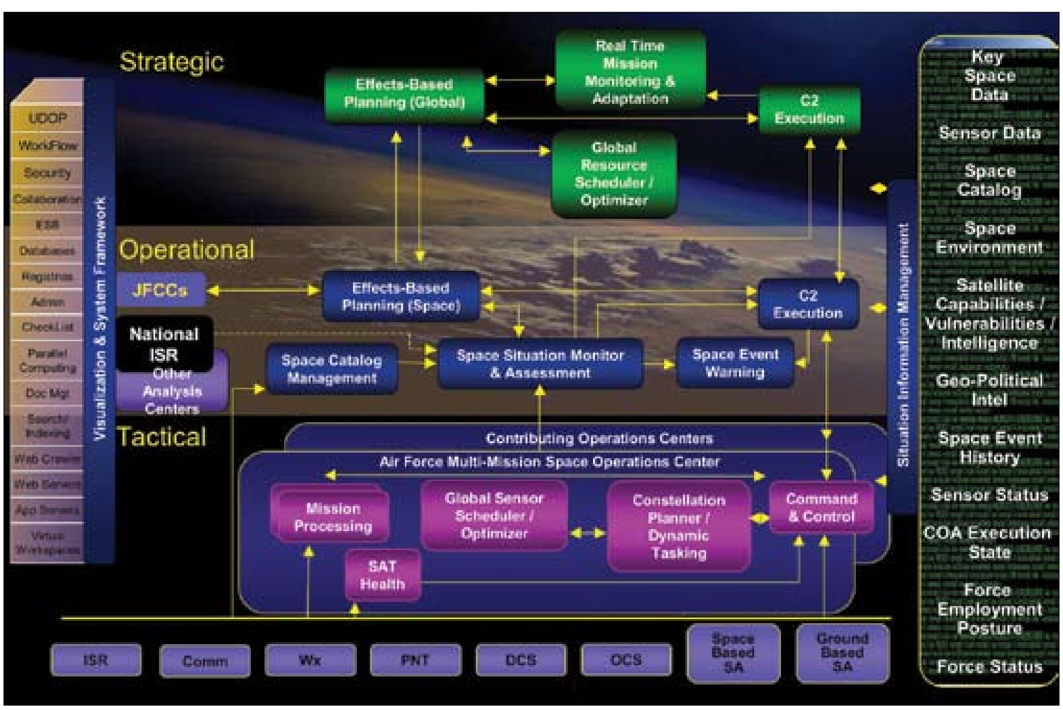


Figure 2. Space Functional Architecture View.

environmental, space system attributes and characteristics) into a fused battlespace awareness picture. The first step is identifying existing data sources and then net-centrically subscribing to the data sources. For the first step, Lockheed Martin surveyed 14 of about 50 programs and identified hundreds of pieces of information that are readily available or could be made available in the near term. We recommend that the government complete this study and expand it to include other contracts to identify data that is available or that could be made available to support space operations.

The second step is to net-centrically subscribe to this data. In the Lockheed Martin study, we identified ready sources of data, for example, Distributed Common Ground Systems (DCGS). In other cases there are systems where data could easily be made net-centrically available. For example both Space-based Infrared System (SBIRS) and Combatant Commander's Integrated Command and Control Systems (CCIC2S) are making their data net-centrically available and have shown inexpensive ways to make their data available, not only to the space community, but to other domains as well.

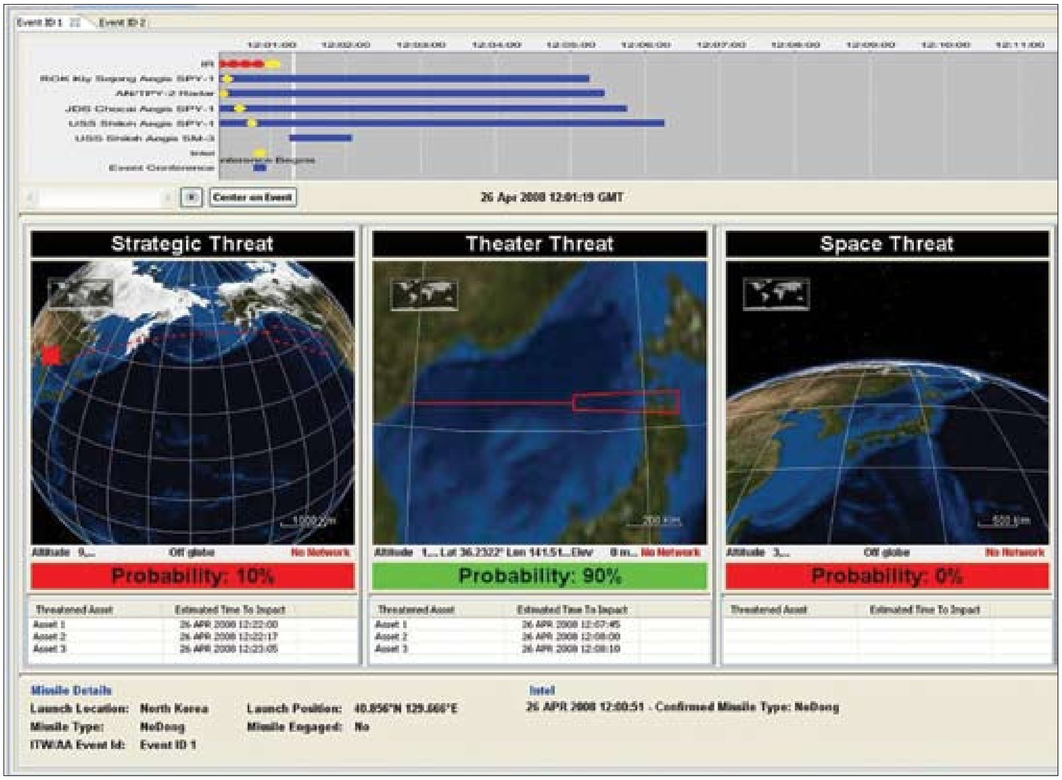


Figure 3. Joint Space Operations Center Commanders Level Commander Launch Event User Defined Operating Pictures.

The third step to is to associate (and eventually fuse) this data into meaningful SSA information and decision quality information. For example, a Joint Space Operations Center Commanders level UDOP for space launch events has been prototyped using DCGS, SBIRS, and CCIC2S data as portrayed in figure 3. With the impending missile defense sensor data made available, a clearer picture of "what is happening," "how accurately do I know what is happening," and "what is affected" is known in real time providing a common picture of space launch events and its impact to national security objectives.

The third element is continuing to develop a more accurate space catalog. A precision space catalog with attendant propagation techniques enables knowing space object locations more accurately and in many cases, with better discrimination.

The fourth element is the 'heart and soul' of SSA. The situation monitor and assessment element is the situation model itself—event-based, anticipatory, and predictive. It is here that the data from the second and third element is appropriately integrated and fused by identifying the context for the data to be used, from the high precision space catalog to associated space object metadata—space system attributes, characteristics, and relationships. Consideration is made not only of the situational knowns, but the known unknowns, the expected, the observed, as well as the expected but not observed. Situational awareness intrinsically harbors persistent uncertainties, so in order to mitigate the 'fog of war,' all these fundamental elements of awareness must be presented to the decision maker to juxtapose the known from the unknown. Within this context, a threat may emerge and be anticipated to enable proactive and pre-emptive action.

The fifth element, an effects-based planning capability is now able, with the predictive results described above, to enable deliberative development of COAs against specific events of operational interest to yield pre-planned activities, concepts for execution, and identify factors to assess the effectiveness of action. These COAs can be presented to United States Strategic Command (USSTRATCOM) and Combatant Commands to respond to changing events affecting planned or executing commanders' intent or to optimize and retask Joint Functional Component Command space units to provide refocused ISR or environmental assessments.

The last element provides for optimizing future space ground capabilities. This optimization is two fold: synergy of tasking Air Force Space Command (AFSPC) assets and in operations and maintenance (O&M) cost savings. The deployment, whether physical or logical of a multi-mission space operations center capability will allow AFSPC to maximum synergy of tasking and in reuse and commonality of associated O&M. A key element in effecting a more accurate and timely ISR capability will be establishing a chain of custody to determine attribution. With common planning tools among AFSPC assets, a more timely and optimum set of tasking to maintain track custody, for example, can be achieved. Additionally, many of the functions of a special operations commander are common

across missions. By taking advantage of this, personnel training can be simplified and cross training among missions would allow a pooling of resources. Likewise, commonality of infrastructure and some mission capabilities allows for development and maintenance cost savings.

These six information system elements together with the sensor system elements, provide the necessary capabilities to enable superior persistent, predictive, and real-time SSA. Awareness that is anticipatory and predictive gives the warfighter the edge of time to shape a situation in a pre-emptive fashion and to control the battlespace tempo, in order to achieve the intent and objectives of leadership and ensure the success of our national objectives. Operational protection of national space assets requires predictive awareness and pre-emptive action; both of which are key elements of superior protection capability.

Sensing Systems

Lockheed Martin explored a variety of technologies and candidate solutions for sensors and architectures that would provide the necessary performance attributes borne out in our assessment of SSA gaps/needs. Several key premises were established as part of this exploration. First, our knowledge of the adversary and subsequently the threats of the future will always have a level of uncertainty and lead to a conviction that any proposed solution must provide adequate flexibility and adaptability. Secondly, the solutions proposed should lean toward rapid development/solution cycles to address emerging technologies and changing threat parameters. And finally, solutions and architectures should provide appropriate standardization and performance "headroom" to allow higher performing new technologies and system concept of operations (ConOps) to be incorporated in the future without wholesale modification/change.

These premises drive the solution space toward simpler solutions (single sensor/mission systems) with high technology readiness levels to address risk, flexibility, and cycle time as depicted in figure 4 which portrays an Experimental Satellite System-11 class spacecraft. Large multi-mission, multi-sensor platforms have historical development cycles on the order of six to eight years and typically approach $1 billion for first article development and delivery. Small and microsatellite solutions have proven development and fielding cycles of 24 to 36 months and significantly (typically 3X-10X) at lower cost. A secondary but important benefit of smaller platforms is the opportunity for significantly lower launch (and therefore life cycle costs) costs by enabling the use of smaller launch vehicles, multiple satellites per larger launch vehicle or as a secondary payload of opportunity on other planned launches.

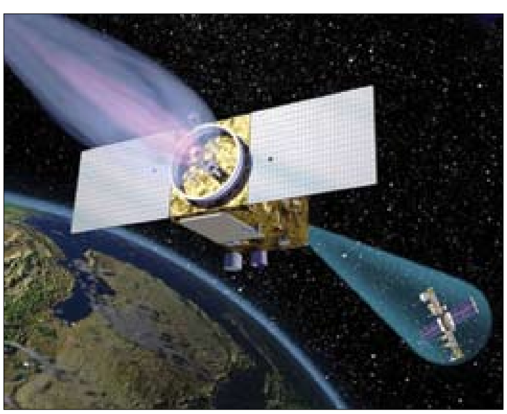


Figure 4. XSS Class Spacecraft.

Many passive sensor technologies such as visible wavelength electro-optic (EO) sensors have dramatically reduced performance during daylight hours (sun in or near the field of view) and as such exhibit enticing gaps in coverage that would likely be exploited by our adversaries. Sensor/architecture solutions for SSA must address these weaknesses in a manner that enables persistent surveillance. Another challenge for passive SSA sensors is presented in range to the object of interest. As the distance to the object in interest increases, the detection sensitivity of passive (such a EO telescopes) sensor is decreased by the square of the distance ($1/R^2$).

While active SSA sensors such as radars are largely insensitive to solar and weather exclusions, the sensitivity/performance of radars is even more susceptible to range ($1/R^4$). For space borne solutions, radars are generally harder to integrate into smaller platforms due to the power necessary to have an effective range. On the other hand, existing technologies are available today to effectively and affordably field large ground based electronically steered array radars to address reasonable range (LEO/ medium-Earth orbit [MEO]) missions within the overall SSA architecture. Today's ground radar technologies also allow for re-programmable and re-configurable ConOps to address a variety of on demand missions, such as new foreign launches and queued high interest/specialized tracks at all altitudes. Affordable and supportable radar solutions can be provided to support SSA general and queued search missions in the near earth regime and tasked missions in MEO/GEO.

For the high altitude SSA missions, several performance attributes drive the sensor solution space, including timely access without solar exclusion, sensitivity, and resolution. Given the EO sensor limitations previously identified, GEO SSA sensors would have a significant advantage by being placed near the GEO altitude. Several unique orbits are available that provide excellent performance against the SSA mission needs in relatively small platform and sensor packages. Microsatellite solutions in a hybrid architecture, often providing overlapping coverage and performance appear to provide the best solution for performance, cost, and flexibility/adaptability for the future. These high altitude solutions combined with supporting sensors on cooperative GEO assets can provide a near and mid-term solution for the SSA mission with extensibility to the far term need.

These basics of sensor solution physics combined with a strong desire to minimize new technology needs (cost, risk, and development time) drive the solution space toward a layered architecture where proven technologies can be applied effectively and affordably to provide the necessary performance at the lowest risk, lowest cost, and least sensitivity to emerging/changing threats and SSA needs. After careful assessment of the necessary attributes of the sensor system, it was determined that a single sensor system operating within a single or layered constellation would be extremely complex, unaffordable, and unattainable with available or near term technologies. The

combined performance attributes of capacity, sensitivity, timeliness, accuracy, and resolution alone would require a multitude of new technological advancements. Based on the results of this SSA sensor solution study, Lockheed Martin recommended a layered sensor solution that effectively utilizes available sensor data from all current sources, utilizes host available resources to add SSA features/sensors to planned government and commercial satellites, initiates spaceborne high technology readiness level (TRL) small or microsatellite solutions to address high altitude needs, and provides distributed ground radar solution to address the lower altitude regimes.

Conclusions

The Lockheed Martin team brought forward a proven systems engineering approach to decomposing the SSA mission area into it's key functional attributes predicated upon the countries need for space protection capabilities. Our analyses were based upon possible threat scenarios that can be foreseen now and in the near term with currently existing technologies that potential adversaries can acquire. The single most relevant conclusion is that SSA must support the entirety of the space superiority mission and must be operated as a cohesive single system. The system must be designed to be flexible and adaptable to evolving threat conditions as security environments evolve. The SSA must prioritize missions by focusing on the highest or most immediate threat with the foresight of understanding our vulnerabilities to provide significant operational utility to the warfighter.

Our study results highlighted several key needs both in the information systems and underlying infrastructure required for the mission as well as several new sensor systems in conjunction with planned upgrades to the existing SSN. In the information systems domain, a key finding is to leverage existing US Air Force investments in standards based SOAs that are able to incorporate new data sources rapidly as well as being able to process multiple security levels. The information infrastructure must be adaptable to incorporate new sensing systems and be able to manage the entire sensing system with a dynamic and adaptive planning function at its core.

The technologies for both the information systems and sensor systems are at a very high TRL; in many cases the space sensing systems have flight proven heritage. The sensing system must be architected as a comprehensive system that includes both terrestrial as well as space based sensors. The most critical information deficit is at GEO and therefore must be focused on first. The potential threat is small enough that to fully understand and characterize it, sensors need to be in GEO. By using high TRL small satellite solutions, the nation would be able to provide high performance and high responsiveness at a much lower cost. The use of proven information and sensing systems can substantially lower the development, deployment, and operations costs for a future SSA system.

Mr. Phillip D. Bowen (AAB, Anderson College, South Carolina; BS, Engineering, Clemson University, South Carolina) currently serves as director of the Surveillance and Intelligence Systems mission area for the Lockheed Martin Space Systems Company. He is responsible for executing the development and delivery of critical national level programs as well as defining, developing and capturing new business opportunities. His mission area has responsibility for Space Superiority programs and Rapid and Responsive Space programs, which includes Operationally Responsive Space.

Mr. Bowen previously held the position of director, Global Surveillance and Intelligence Systems and Space Radar program. His primary responsibility in this role was management of the Space Radar program and for expanding Lockheed Martin's role in radar related technologies both domestically and internationally. Mr. Bowen joined Lockheed Martin in 1979 and has held progressively responsible positions within the company covering all phases of program development and execution.

Mr. Clifton Spier (BA, Mathematics and Computer Science, San Jose State University) serves as the director, Strategic Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance Capabilities Unit for Lockheed Martin Information Systems and Global Services, Mission and Combat Support Solutions located in Colorado Springs, Colorado. He is responsible for executing the development and delivery of operational and strategic level command and control programs, as well as defining, developing, and capturing new business opportunities. His business area is responsible for supporting USSTRATCOM, NORAD, NORTHCOM, and Air Force Space Command elements evolving from legacy systems and centers to new standards based, separate operating agency architectures across space, air, and missile mission areas. His unit also includes an expanding presence into the commercial market place with evolving First National Bank of Nebraska systems work, the Federal Drug Administration, the Department of Homeland Security, and the Veterans Administration and international opportunities leveraging his business areas personnel and skills.

Mr. Spier served in the US Air Force from 1978 to 1982 in space operations and acquisition. Upon leaving the service he joined Lockheed Martin (formerly IBM Federal Systems then Loral Federal Systems) in 1982 and has held progressively more responsible positions within the company including deputy program manager CCSE/C&DP; ReARC program manager; SIP program director; IEC program director; director, SBIRS Increment 2 Ground; and director, ISC2 programs. He is a graduate of the Defense System Management College Advance Program Management Course (APMC 95-2).

Action-based Approach for Space Protection

Mr. Steven Prebeck
Site Manager, Operations Support Program
Raytheon
Colorado Springs, Colorado

Mr. Kenneth Chisolm
Engineering Fellow, Chief Engineer
Raytheon
Rocky Mountain Engineering
Aurora, Colorado

The Space Protection Problem Set

More than any other nation, the United States relies on space operations for its military, civil, and economic activities. These operations provide the critical force multiplier that has been key to US military success during the past two decades. The United States' involvement in space started primarily to support military activities (communication, intelligence and reconnaissance, and navigation) in addition to civil (primarily meteorology and remote sensing) and commercial (communications) activities.

Since our first satellite launch in 1958, space has become more and more commercialized. During the past two decades, civil users have carved out markets in communications and remote sensing. We have also seen a greater dependency on our military utilization of commercial space services to augment capabilities. As a result, it is imperative we protect the space assets that are so vital to our national security and economic interests.

In the 1970s, the Soviets developed and successfully tested a direct ascent anti-satellite weapon (ASAT) capable of intercepting low-earth orbit targets. To level the playing field, the US developed an air-launched ASAT capability. These offsetting chess moves remained the status quo through the Cold War and beyond. A decade ago, in the National Defense Industrial Association's 1998 Summer Study on Space for United States Space Command,[1] General Howell Marion Estes III posed the following questions to industry: "What does industry want?" and "What is industry's position on space protection?" At that time, and until recently, the primary perceived threat to on-orbit assets was environmental effects. The study stated, "There was no consensus among commercial representatives that there was any credible threat that would justify overt protection measures. Even if there was a threat, there was no consensus that commercial space required protection. The increasingly multi-national nature of commercial space makes unilateral threats unlikely."

In short, the perceived threat was not great enough for commercial satellite operators to expend precious on-orbit weight and power to incorporate onboard protection measures at the expense of revenue-generating payload capabilities.

Recent Events – Emerging Threats

In January of 2007, the Chinese successfully launched a direct ascent ASAT from their Xichang region and destroyed their defunct Fengyun 1C weather satellite. The Fengyun 1C weather satellite circled Earth in a low-earth, sun-synchronous orbit at an altitude of 860 kilometers. This capability by the Chinese places commercial imaging and civil meteorological satellites operating in this orbit regime at risk. Figure 1 shows this event and other potential threats.

In addition to ASATs, other emerging capabilities can negatively impact satellite services, short of destroying a satellite. A growing concern for the US is the deployment and employment of radio frequency jammers against satellite systems, much as the Iraqis used to affect Global Positioning System signals around Baghdad in the early stages of Operation Iraqi Freedom. For instance, various countries are developing laser systems that could 'dazzle' a satellite's electro-optical sensors and temporarily blind it. Other countries are developing or purchasing micro-satellites that, because of their size, are able to escape detection by US ground- and space-based space tracking sensors. This new "micro" class of satellites has the potential to impact US or friendly satellite operations.

The establishment of the Space Protection Program on 31 March 2008 by the commander of the Air Force Space Command and the director of the National Reconnaissance Office is a formal first step to developing an integrated protection approach for US and allied space systems.

Figure 1. Chinese ASAT event showed viable threat to satellites.

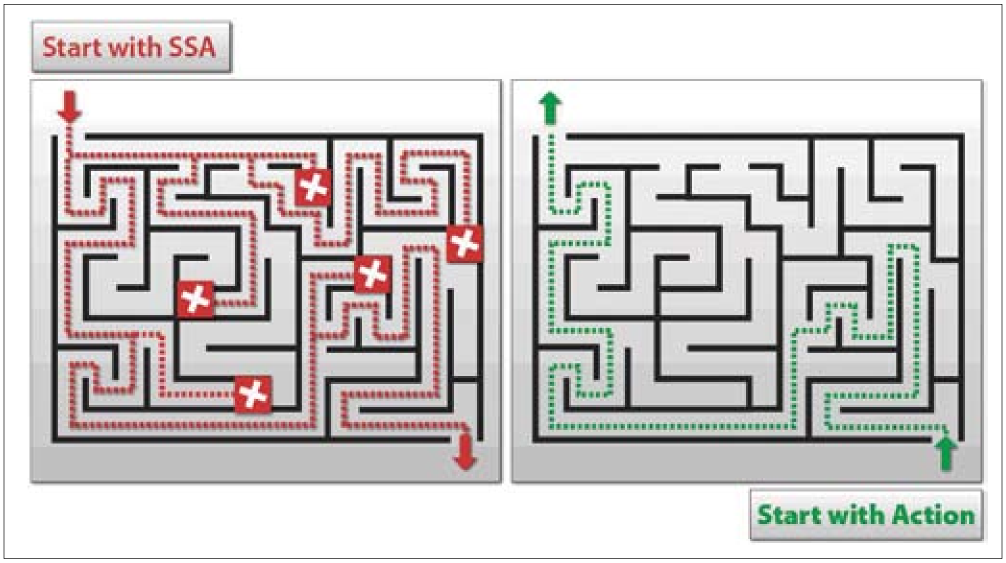


Figure 2. Maze analogy for reverse engineering a Space Protection problem.

Gaps – Sensors and Data

The traditional approach for dealing with space threats is to fully understand everything that is happening in space to determine if these threats impact assets. This approach, in turn, drives the tasking and generating of large amounts of data from ground- and space-based optical, infrared, and radar sensors of the space surveillance network. The space-based assets of the US Air Force Defense Support Program (being replaced by the Space-Based Infrared System) and other space-based assets augment this network. Constraining this data collection is the limit in the volume of space that our existing sensors can survey at any given time. Gaps in this sensor coverage contribute to space situational awareness (SSA) limitations. A long lead time exists for procuring and deploying new ground-based assets, with even longer lead times for new space-based assets in eliminating some of these coverage gaps. Considering these gaps, our existing assets still produce huge amounts of data that correlate and fuse to find information that is relevant to a particular activity or asset of interest—this data analysis is time and manpower intensive.

Action-Based Approach – A Different Way of Looking at the Space Protection Problem

An alternative approach to tackling the problem is to start at the desired operational end state, and reverse the process to determine the specific data needed to enable actions that result in that state. This approach greatly reduces the amount of data for collection, fusion, and analysis. Figure 2 shows a simple illustration of this approach by working through a maze. The traditional way of starting at the beginning of the maze and working through it may lead to multiple dead ends and delays, while starting at the desired action or end point allows working through the maze without dead ends and delays.

Following the maze analogy, an alternative to learning everything about every object in space is an action-based approach. For any given potential threat, desired objectives exist for countering the threat. These objectives are achieved by effects, which in turn are enabled by specific actions. Effects planning, delivery, and assessment require data for situational awareness. Rather than using the current approach for aggregating and integrating all SSA information, the action-based approach aggregates specific actions, and only pulls together data and information needed to support these actions. Figure 3 shows this action-based approach.

Once the asset's orbit domain is determined and the threat is defined as ground- or space-based, one can work quickly from left to right in the figure, along specific threads for each desired effect or action. Ideally, for a given effect or action, tactics, techniques, and procedures (TTPs) associated with data requirements are needed for implementation exist. Unforeseen scenarios also exist where TTPs and information needs develop as a situation evolves. The analysis, planning, and execution complexity of the TTPs, and their associated data needs with ad hoc requirements dictate the level of battle management and command and control needed to deliver space effects. The key is that the analyst obtains only relevant data from all source data, eliminating the need for time-consuming sorting and fusion of entire data sets.

A specific example of an action-based approach is the threat

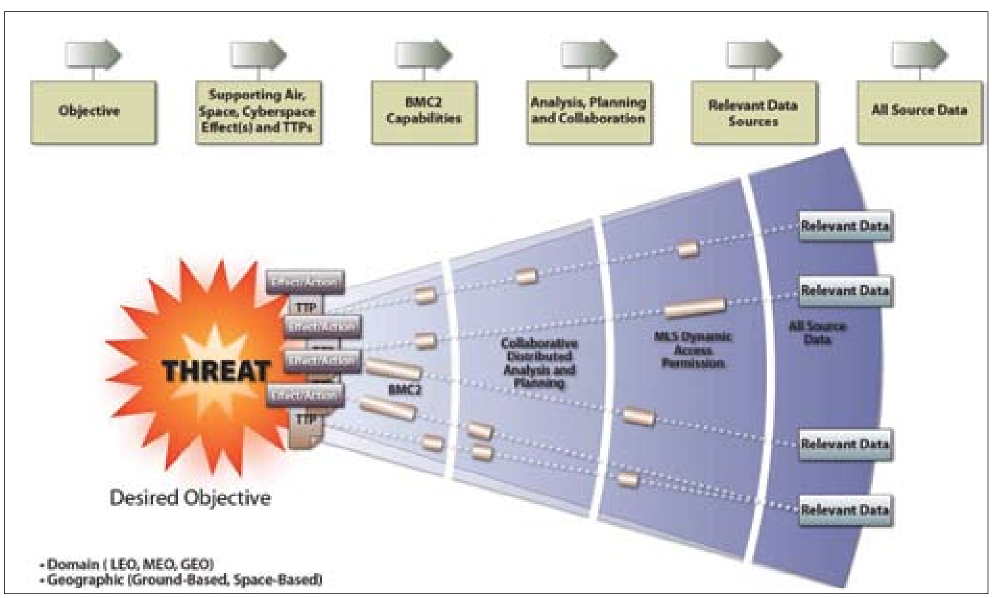


Figure 3. Action-based Approach for Space Protection.

of an adversary's laser weapon delivering short duration dazzling of an imaging satellite. The desired objective is to ensure the United States' continued ability to perform space-based intelligence, surveillance, and reconnaissance (ISR), anywhere and any time. To accomplish this objective, a possible course of action is to deny the adversary's capability (be it diplomacy, avoidance, or other action). This action requires geolocation of the laser dazzler. Geolocation is supported by reconnaissance, anomaly detection by the satellite, characterization of the anomaly, attack assessment, and intelligence gathering on the specific threats. These activities are decomposed to identify the critical elements of data needed to perform the functions (for example, overhead imagery, Intelligence collections, telemetry, and weather data). These activities are also decomposed to determine how this data fuses to provide the warfighter with the essential elements of information that enable selecting and executing courses of action aimed at achieving the end state.

A key enabler to this approach is establishing rapid prototyping programs and facilities to develop and evaluate new capabilities quickly. Raytheon has established the Battle Lab for Space Superiority Technology, with both unclassified and sensitive compartmented information labs operational. The development activities in these facilities provide several advantages. First, the development activities produce usable prototypes and capability in a quick reaction environment. Second, they provide insight to enable improved concept generation and evaluation. The benefits to the systems engineering process help focus requirements assessment, generation, and deployment of capabilities that are more relevant to the warfighter's needs, on accelerated timelines.

Summary

The recently announced Space Protection Program has the potential to make a difference in protecting space assets so vital to our national security and economic interests. However, we must still overcome the problems facing us today: large amounts of data to process into information and knowledge from our existing sensors, and gaps in our SSA coverage.

To be effective while constrained by limited ISR resources and data access, the United States must be efficient in its prosecution of threats: tasking for and using only what is needed to successfully understand threats, and then deliver the effects. We historically begin gathering and tasking for all available information before we have determined a desired objective. The approach discussed in this article provides a better use of limited resources—link effects to an objective, select appropriate TTPs, gather relevant available data, and task for additional data as needed. Space effects must be decisive to support clearly defined objectives that provide relevant and tailored information in a timely manner.

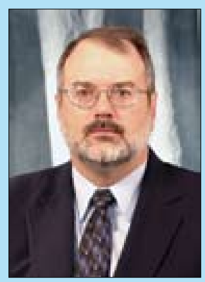
Notes:

[1] 1998 Summer Study on Space, National Defense Industrial Association, December 1998.

Mr. Steven R. Prebeck (BS, Aviation/Meteorology, University of Illinois; MBA, University of South Dakota; MS, Airpower Studies, School of Advanced Airpower Studies; MS, National Security Strategy, National War College) directs operations of Raytheon Company's Operations Support Program site in Colorado Springs, Colorado.

Mr. Prebeck's Space Control experience began with his assignment as the operations officer for the 17th Test Squadron. He then took command of the 5th Space Surveillance Squadron at Royal Air Force Feltwell, United Kingdom. Following his squadron command, he moved to be the deputy commander for the 21st Operations Group where he led all activities for the passive space surveillance squadrons. His final Space Control assignment was as the chief of Counterspace Operations at Air Force Space Command Headquarters where he led an integrated counterspace mission team providing policy and guidance for the offensive counterspace, defensive counterspace, and space situational awareness mission areas.

Mr. Prebeck served in the United States Air Force from 1979 to 2005. He was awarded the Legion of Merit with one oak leaf cluster, the Bronze Star Medal, the Meritorious Service Medal with five oak leaf clusters, the Air Force Commendation Medal, and the Air Force Achievement Medal. He is a graduate of Squadron Officer School, Air Command and Staff College, the School of Advanced Airpower Studies, and National War College. He is also certified by the Project Management Institute as a Project Management Professional.



Mr. Kenneth D. Chisolm (BS, Electrical Engineering, South Dakota School of Mines and Technology) is a Raytheon Engineering Fellow and the chief engineer for Raytheon Company's Rocky Mountain Engineering organization, supplying technical expertise to Raytheon sites in Aurora and Colorado Springs, Colorado, and Omaha, Nebraska. He is also the technical director for a Raytheon-wide research and development activity focused on space control activities.

Mr. Chisolm has fourteen years of space control experience including leading numerous technical studies and supporting space-control related pursuits and programs. He was an analyst on the Space Control Architecture Development Team at the Department of Defense Office of the Space Architect where he developed architectures for offensive counterspace, defensive counterspace, and space situational awareness mission areas. Recently, he was the lead architect for the Raytheon GPS OCX proposal team, and the chief engineer for the Raytheon Transformational Satellite Mission Operations System study and proposal. Prior to his space-related activities, Mr. Chisolm was a system engineer on various airborne fire control radars.

Mr. Chisolm has been employed by the Raytheon Company (formerly Hughes Aircraft Company) since 1985. He is a graduate of the Raytheon Certified Architect Program and is one of 73 Raytheon Certified Architects in the company. He is also a graduate of the Hughes Radar System Engineering Development Program. He serves on the Raytheon Corporate Architecture Review Board, and holds certifications from The Open Group as an Open Group Architecture Framework-8 Architect, and the Software Engineering Institute as an Architecture Tradeoff Analysis Method Evaluator.

Walking the Walk, Integrating Space Effects Planning into Ground Operations Now

Lt Col Stuart A. Pettis, USAF
Commander, 1st Air Support Operations Squadron
Wiesbaden Army Airfield, Germany

Overview

In the February 2008 issue of the *High Frontier,* Maj John Thomas and Maj Rich Operhall presented a compelling argument for why space and cyber effects planners need to be better integrated with ground maneuver units below the corps level and how these planners can be integrated with existing Air Force air support operations groups, air support operations squadrons (ASOS) and tactical air control parties (TACP). Although I am a core space officer (W13S), in 2007 I was fortunate enough to become an air liaison officer (ALO) in the 1st ASOS, supporting the US Army's 1st Armored Division. In 2007, I took command of my squadron and then deployed to Operation Iraqi Freedom where I served as the expeditionary squadron commander and ALO for Multi-National Division North. Based on my experience, Majors Thomas and Operhall are spot on. However, I believe they stopped short and the time is right to address the nature of the air liaison officer and tactical air control parties.

Tactical Air Control Parties

All airmen know the role of the Air and Space Operations Center (AOC) within the joint theater air control system. Fewer understand the role of TACPs within this construct. Per Air Force Doctrine Document (AFDD) 2-1.3, Counterland Operations, "*Tactical Air Control Parties serve as the principal Air Force liaison element aligned with Army maneuver units for corps through battalion. The primary mission of corps through brigade-level TACPs is to advise their respective land commanders on the capabilities and limitations of air and space power as well as assist the ground commander in planning, requesting, and coordinating close air support.*"[1]

In layman's terms, TACPs are the only airmen in a ground unit headquarters and are charged with representing the full array of Air Force capabilities to the ground commander. Traditionally, a TACP's primary role is to assist the ground unit in integrating close air support (CAS) into their scheme of maneuver and then overseeing execution of CAS. This mission traces its origins to World War II and to Lt Gen Elwood R. "Pete" Quesada, who placed pilots with radios into armored columns.[2]

TACPs are aligned to battalion, brigade, and corps levels as shown in figure 1 below.[3] At the battalion level, a TACP often consists of two airmen, one of whom is a Joint Terminal Attack Controller (JTAC), a highly senior noncommissioned officer skilled at integrating and controlling CAS. A brigade TACP consists of an air liaison officer (ALO), a rated officer (usually a major or captain), as well as several JTACs and airmen. The brigade TACP integrates airpower into the brigade's scheme of maneuver as well as oversees the activities of the battalion TACPs within their unit. A division TACP, which resembles a brigade TACP but also adds squadron functions such as maintenance and supply, is led by a lieutenant colonel and has several ALOs under their command. They also oversee the operations of the brigade and battalion TACPs within their unit. The corps TACP, known as the corps ALO containing the air support operations center, oversees the operations of all the TACPs within a theater. It is led by a colonel who also serves as the expeditionary group commander. The corps ALO is the senior USAF liaison to the corps, but works directly for the joint forces air component commander and interacts directly with AOC, integrates air into the corps scheme of maneuver and processes immediate requests for CAS. Besides group-level functions, it also adds numerous intelligence professionals to TACP operations.

Because they serve as the single face of the Air Force to numerous Army units, TACPs have always represented other Air Force functions while maintaining their core competency of CAS integration and control. There are also air mobility liaison officers (AMLOs) corps and divisions levels. These officers are

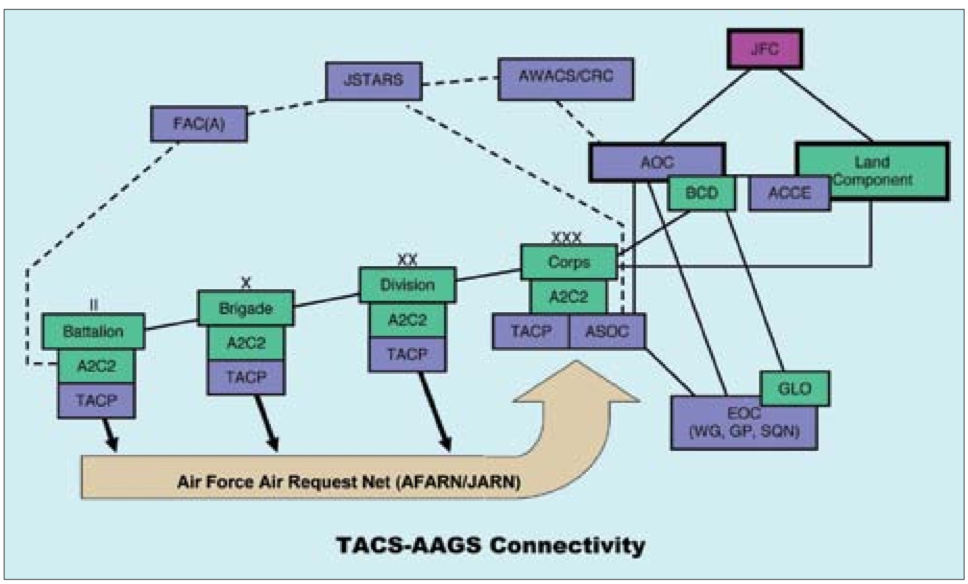


Figure 1. Key Air Force and Army components of the Theater Air Control System—Army Air-Ground System.

The single space planner on the ACCE staff integrates well with both Multi-National Force-Iraq (MNF-I) and Multi-National Corps-Iraq (although the current charter of the ACCE is to only support MNF-I), but as a one-deep position also is not in a position to cover tactical level unit planning and execution.

"specially trained to implement the theater air control system and to control airlift assets engaging in combat tactics such as airdrops."[4] Also, in addition to the intelligence personnel assigned to the corps TACP, intelligence, surveillance, and reconnaissance liaison officers (ISR LNOs) were added to division TACPs in Operation Iraqi Freedom in 2007 and beginning in 2009 will be permanently assigned to Air Support Operation Squadrons with division TACPs. These officers integrate Air Force ISR capabilities, improve intelligence requests, increase AOC awareness of intelligence needs and support TACP intelligence requirements.[5]

Current Space Integration into Ground Operations

Currently, Air Force theater space personnel reside in the Combined Air and Space Operations Center with a single Air Force space planner forward deployed to the air component coordination element in Iraq and a single Air Force space planner forward deployed to the joint space support team in Iraq. Supporting these personnel is the Joint Space Operations Center at Vandenberg AFB, California. However, there are no space personnel deliberately assigned to a TACP similar to AMLOs and ISR LNOs.

The Army identified this knowledge gap as an issue and developed Functional Area 40 (FA40) several years ago. Unlike an Air Force specialty code, members of functional areas come from Army branches such as artillery or military intelligence and compete for admission into a functional area after seven years of service. They are then tracked, developed, and assigned to staffs where they provide commanders with "expertise and guidance on conducting the space component of operations, which enhances a command's ability to task, collect, process, and act on space-based products, information, warnings, and space-related capabilities."[6] At the corps and division level, there are one or two FA40s, known as a space support element (SSE). In addition, US Army Forces Strategic Command provides Army Space Support Teams which can plus up an SSE as required. Figure 2 below shows how space expertise is currently integrated in both the air and ground components.[7]

Coming from other branches such as infantry or artillery, FA40s have an intimate understanding of Army operations. To gain an understanding of space operations, they attend an 11-week, intensive academic program of instruction which covers topics such as space environment, space control, force enhancement, analytical tools, and joint space capabilities. They can also attend Air Education and Training Command, civilian institution and National Security Space Institute courses.[8]

Limitations with Current Space-Ground Integration

From Operation Desert Storm to the present our focus has been on integrating air and space operations. This challenge was significant enough to monopolize our time and efforts. However, for the past decade we have successfully integrated air and space operations through personnel assigned to air operations centers and our directors of space forces. We can now focus on integrating space with other components.

An obvious question is can Air Force theater space personnel, who are assigned to the combat air operations center (CAOC) and the air component coordination element (ACCE), integrate space effects into brigade and battalion operations? CAOC space operators do amazing work but their focus is on the internal processes of the CAOC and not on individual ground unit plans. Also, given that there are one corps, four divisions, and over 20 brigades in Iraq, each planning synchronized but unique operations, it is unlikely they could support each unit. The single space planner on the ACCE staff integrates with both Multi-National Force-Iraq (MNF-I) and Multi-National Corps-Iraq (although the current charter of the ACCE is to only support MNF-I), but as a one-deep position it is not in position to cover tactical level unit planning and execution. Finally, the Army, more than any other service, relies on face to face contact during planning … they also expect personnel to pull information through common operating pictures and shared information

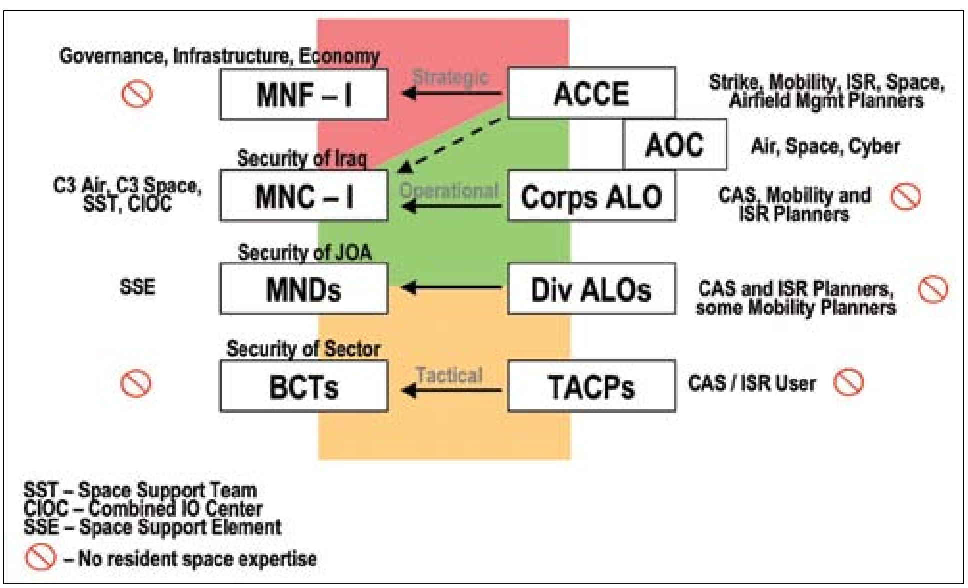


Figure 2. Integration with the Ground Component.

servers.

The challenges that the US Army counterparts face are daunting. Global Positioning System (GPS)-aided navigation is now standard as are GPS-aided artillery munitions. Ground forces are extremely reliant on satellite communications and as the number of patrol bases increases, these requirements will also increase. We are also operating in two countries adjacent to Iran, whose ballistic missile capability is increasing at a time when demands for base operating units and transition teams are stressing air defense artillery manning. There is also increasing awareness and use of specialized space capabilities, even at the division level.

FA40s are doing outstanding work, but do not bring a space professional's years of technical systems experience to problems. Air Force space operators spend years just conducting space operations and attend rigorous space-specific training throughout their careers. Those selected for duty in theaters are usually the best we have to offer and are in most cases weapons officers. Pairing an FA40 with a US Air Force space operator brings both a US Army perspective and a depth of space knowledge to challenges. This approach mirrors the relationship that ALOs have with members of the Fire Support Element within each Army echelon and unit. Doing this also follows a trend of jointness descending to tactical level operations identified by RAND Corporation and other studies.[9]

Figure 3. A soldier from the 172nd Stryker Brigade Combat Team shows an Iraqi soldier how to navigate using a map and GPS prior to an Iraqi-led operation near Mosul.

Way Ahead

An obvious way to address this need is by adding space professionals, similar to AMLOs and ISR LNOs, to TACPs. Because this follows an established model, it should be very palatable to both the Army and Air Force. To meet the intent of pairing these individuals with FA40s, they should be added only to those ASOSs which have a division TACP which is where ISR LNOs are also placed. With only 10 active-duty divisions in the Army, this is not a sizeable requirement.

Rather than deploy as individual augmentees, these individuals should be assigned to each ASOS so that they can train with both their ASOS and aligned division. This will allow them to train with the division staff and also learn battlefield airman skills. As stated before, the Army is very reliant on face to face contact and each division operates with a slight difference. Battlefield airmen skills, such as advanced weapons familiarization, combat lifesaver training, and convoy live-fire drills, are also critical given TACP operating locations.

A less obvious solution is to select space operators to serve as ALOs. This is a radical departure from the current philosophy which is that only fighter/bomber personnel who intimately understand CAS and have "air sense" can serve as ALOs. As AFDD 3-1.2 states, *"An ALO is a rated officer, aligned with a land maneuver unit, who functions as the primary advisor to individual land commanders on the capabilities and limitations of air power. Acting as a land commander's expert on air and space operations, ALOs must be involved in the supported land commander's military decision-making process (MDMP) so they can perform detailed air support planning with their own staff."*[10]

Despite the stipulation that an ALO be a rated officer, none of the requirements listed seem to preclude a non-rated officer from serving as an ALO. The requirements are that he or she be an advisor, an expert on the capabilities and limitations of air power, be an expert on air and space power and be involved in a ground commander's MDMP.

Based on my experience, I would further break the required knowledge down as follows:

An ALO must:

- Understand the capabilities and limitations of US and coalition aircraft (including unmanned aerial vehicles) performing CAS.
- Understand munitions capabilities and limitations and options for limiting collateral damage.
- Understand airspace control measures.
- Understand joint, Air Force, and Army doctrine relating to CAS.
- Understand the theater air control system and CAOC processes.
- Thoroughly understand joint terminal attack control procedures.
- Understand the Army's MDMP and orders process.

None of the requirements in either doctrine or my break down require "air sense." In fact, our battalion air liaison of-

A less obvious solution is to select space operators to serve as ALOs. This is a radical departure from the current philosophy which is that only fighter/bomber personnel who intimately understand CAS and have "air sense" can serve as ALOs.

These officers would train and deploy with Army combat units, integrate at the tactical level, and gain incredible experience. The benefits to the Air Force and AFSPC, with this type of experience returning would be immeasurable.

ficers are enlisted personnel. Given that this is the tip of the spear, the case is already made that personnel without flying experience can serve as ALOs.

This is not to say that there would not be a very steep learning curve for a space operator to become an ALO. Few officers coming straight from an Air Force Space Command (AFSPC) crew assignment would have the prerequisite knowledge. However, our space weapons officers and, in particular those on second assignments after serving in a theater AOC, have this knowledge. Any knowledge gaps for these officers would be offset by mandatory training such as the ALO Qualifying Course. Creating a "space ALO" from scratch without selecting space weapons officers would be extremely difficult but not impossible. However, training using weapons school or advanced space training courseware, the ALO Qualifying Course and courses on doctrine could be easily built.

There are benefits beyond just integrating space into ground operations. Over the last several months the Air Staff has looked at ways they can continue to provide rated operators to unmanned aerial vehicles, ALOs, and command and control assignments and still maintain pilots in cockpits. Numerous options have been explored including creating a permanent ALO career field similar to special tactics. Providing some space operators to offset rated officers helps the Air Force as a whole.

This would also provide a core of space operators with very unique, tip of the spear combat experience. These officers would train and deploy with Army combat units, integrate at the tactical level, and gain incredible experience. The benefits to the Air Force and AFSPC, with this type of experience returning would be immeasurable.

Conclusion

Although the Air Force is the lead service for space, we have neglected the integration of Air Force space expertise with ground operations. We have instead relied on another service to be the advocate for our capabilities. It is inconceivable that we would do this for fighter, bomber, or air mobility assets. We need to have Air Force space operators advocating Air Force space capabilities. They can partner with Army space personnel, but ultimately this is our mission. By utilizing the existing ASOS and TACP structure we can integrate space operators into Army tactical level operations almost immediately. We should also pursue having space operators fill at least a few ALO billets. The benefits to the Air Force, Army, and space operations make this an imperative.

Notes:

1 Air Force Doctrine Document (AFDD) 2-1-3, *Counterland Operations*, 11 September 2006, 63.

2 Thomas Alexander Hughes, *Overlord: General Pete Quesada and the Triumph of Tactical Air Power in World War II* (New York: Free Press, 1995), 141-169.

3 AFDD 2-1.3, *Counterland Operations*, 52.

4 AFDD 2-6, *Air Mobility Operations*, 1 March 2006, 62.

5 Capt Ryan T. Hudson, *TACP Intelligence Operations*, USAF Weapons School Paper, Nellis AFB, Nevada: 19th Weapons Squadron, 2008.

6 United States Army Human Resources Command, Functional Area 40 website, "What is FA40," http://www4.army.mil/FA40/index.php.

7 Maj John Thomas, "Air, Space, and Cyberspace Integration with the Ground Component," briefing to the 2008 Space Symposium, June 2008.

8 United States Army Human Resources Command, Functional Area 40 website, "What is FA 40," http://www4.army.mil/FA40/training.php.

9 Bruce R. Pirnie, Alan Vick, Adam Grissom, Karl P. Mueller and David T. Orletsky, *Beyond Close Air Support: Forging a New Air-Ground Partnership* (Santa Monica: Rand, 2005), 36-38.

10 AFDD 2-1-3, *Counterland Operations*, 11 September 2006, 62.

Lt Col Stuart A. Pettis (BS, Florida State University; MS, University of North Dakota; MS, Air Force Institute of Technology) is commander of the 1st Air Support Operations Squadron, Wiesbaden Army Airfield, Germany. He leads battlefield airmen providing tactical air control parties for the global war on terrorism and is also the air liaison officer for the United States Army's historic 1st Armored Division. Between October 2007 and May 2008, he was the commander of the 1st Expeditionary Air Support Operations Squadron and the air liaison officer for Multi-National Division North during Operation Iraqi Freedom. A career space operator, Colonel Pettis has served in a variety of duties in the Missile Warning and Space Control mission areas. He also served as the executive officer and chief of Space and Information Operations Plans for Third Air Force as well as the head of tactics development for Air Force Space Command's tactics squadron. He is a graduate of the United States Air Force Weapons School and a contributor to the book *Space Power Integration: Perspectives of Space Weapons Officers,* published in 2006 by Air University Press, as well as to *Air and Space Power Journal's* online journal *Air Chronicles*.

Are you a Sam or a Courtney?[1]

Lt Col Robert J. Vercher, USAF
Commander, 12th Missile Squadron
Malmstrom AFB, Montana

Lt Col Andrew S. Kovich, USAF
Commander, 90th Maintenance Operations Squadron
F. E. Warren AFB, Wyoming

"I had been accustomed throughout my life to classify all public servants into one or the other of two general categories: one, the men who were thinking what they could do for their job; the other, the men who were thinking what the job could do for them."[2] ~ Henry Stimson, Secretary of War 1909-1911; Secretary of State 1928-1932; Secretary of War 1939-1945

There are many "how to" articles written about the art of leadership; this is not one of those articles. Rather, this article will ask more questions than it answers and simply serves as the extension of an on-going leadership discussion between the two authors. A discussion that often starts with the questions: "are you a Sam on that issue or a Courtney" or, "is that person acting like Sam or Courtney?" We hope this article will encourage individuals who study the art of leadership to view this dynamic and complex subject through the lens of two characters. Sam Damon and Courtney Massengale are army officers portrayed in Anton Myrer's novel *Once An Eagle*. The stories of these two officers contain themes worth exploring by today's officer and enlisted corps. Among them are: heroism, good versus evil, ethics and morality, corruption of power, career over family, devotion to country, and unchecked ambition. Charles C. Krulak, former commandant of the United States Marine Corps stated that this story "has more to teach about leadership … than a score of modern-day management texts. It is the primer that lays out, through the lives of its two main characters, lessons on how and how not to lead."[3] The question is which officer is the "how" and which is the "how not."

As a member of the military, our focus is often on what a military member does as opposed to what we actually are, or should be.[4] Right now we are all working hard to learn our role. Duty performance is critically important but one should stop and take the time to think about what they are meant to be—a leader, commander, noncommissioned officer in charge, superintendent, or chief. How will I act in that role? Whom will I emulate? As members of the profession of arms there is an intentional focus on building the foundation for future success today. Therefore, it is important to ask: What is my vision for my future self?[5] Will I be like Sam or be like Courtney? To help build a vision of our future selves, this article relates the stories of two officers; both of whom are aggressive, educated and devote countless hours to studying their profession. Both officers serve in America's wars from World War I through Vietnam and are successful. Both officers rise to general officer rank and are given multiple command opportunities. Where the two officers differ is in their approach to leadership and the trust placed in them as commanders.[6]

In the novel, Sam Damon enlists in the army and later receives a battlefield commission during the First World War. He is a natural leader, excellent commander and successful soldier throughout his career. Sam is kind, caring and a selfless servant to the Army, his troops and the nation. He demands excellence from himself and spends countless hours honing his superior combat proficiency. Sam knows that intuition plays a huge role in the success of any commander and that intuition can be developed through the lifelong pursuit of military education which he accomplishes diligently during his off duty time.[7] He is a demanding commander who sets high standards in training in order to achieve success and survival on the battlefield. Probably Sam Damon's most valuable traits are providing vital information to his superiors and giving an honest assessment of every situation, even when it is not popular or could jeopardize his career goals.[8] This is not to say that Sam has no concern for his army career. Rather he purposely chooses the tougher road in his career by never avoiding the controversial issue, never taking advantage of his subordinates, and never engaging in sycophantic behavior to achieve success.[9] Additionally, Sam learns to be careful of those who are willing to display military operations in the very best light possible. In Sam's experience, he finds many superiors to not be interested in the "truth of a long war against a tough, resourceful enemy but in the illusion of a cheap and easy victory."[10] The bottom-line for Sam Damon is to always prepare himself and his subordinates for the next challenge, take care of his troops, and ensure his unit is at the pinnacle of combat capability. Courtney Massengale gains success through a different approach.

Courtney Massengale is a smart, charming, and ambitious officer who studies his profession with the same drive and dedication as Sam Damon. He is poised, polished, and a highly effective staff officer and manager who serves on General "Black Jack" Pershing's personal staff. He is selected to write a guidebook to the battlefields of the First World War, an honor also bestowed on General Dwight D. Eisenhower. Courtney is very adept at balancing army needs with the political realities he faces in Washington DC. He worries about the political fallout from every issue and sees no need to disrupt the course of his career by taking a stand on an issue he can do nothing about. "Why sacrifice myself to no good end" is certainly a motto to which he ascribes. Further, omission of distasteful pieces of news is his primary objective especially if he feels he will be chastised and no change will come from it. If faced with a lack of sufficient men or materials to carry out his mission, Courtney "makes due" with the situation, despite the dangers/losses, rather than challenge his superiors by advocating for a different approach.

Courtney believes it most important to present a positive/can do image to his superiors rather than rock the boat.[11] He is very careful to ensure he makes the right connections inside and outside the army and to hold every position that ensures advancement.[12] Courtney has the opportunity to work closely with senior officers and this certainly provides an unmatched education. As a commander, Courtney takes care to ensure blame is never affixed to his organization, and if it is, to ensure he is not personally held responsible. The success of his organizations (and his organizations do succeed) is always attributed to his command ability and superior tactical skill. Often these accolades are a result of his personal public relations efforts. Courtney is often more concerned about what his troops can do for him rather than what he can do to help the troops carry out the mission. The bottom-line for Courtney Massengale is to always seek out the best opportunities to shine and to ensure that his decisions meet with approval from the majority of his superiors. While some of these examples of Courtney's leadership are certainly negative, there are more subtle examples of his failures in moral courage to which many of us are also extremely susceptible.[13]

Often, our attention can be diverted away from our primary mission or the well-being of our troops. Institutional pressures unrelated to mission accomplishment often consume much of our time and wear down our ability to make honest decisions or provide honest feedback.[14] How does one address these challenges? Is it possible there are redeeming qualities to be found in Courtney's officership? Certainly, there is a seductive or an elusive charm to solving problems like Courtney does. Does it really matter how the job gets done?[15] While Sam approaches every problem or issue through the "frontal assault" method and gets his hands dirty, Courtney seems to rise through the ranks without ever getting his hair mussed. Is it really a tough call to determine which issues to fall on your sword for? Is it valid as a leader to hold back on some issues and live to fight another day for what is right? If you know you will be relieved and replaced by a yes man, should you take action and be relieved? Is the right answer to say "yes sir" and move out even if you know it to be a critical mistake?[16]

Are you a Sam or a Courtney? The question still stands as a viable means of self-analysis or unit analysis. What decisions do you see in front of you, or what leaders do you see around you taking on some of the characteristics of either of Myrer's characters? Is it possible to be all Sam or to be all Courtney, or is it possible that institutional or peer pressures force a combination of the two character types. At first blush it seems like everyone wants to be a Sam Damon. But, what happens if you need to take on a trait found in Courtney Massengale to handle an unyielding boss to accomplish something good for your group or organization?[17] Is that a form of manipulation where the ends justify the means, or does Courtney-like behavior begin to erode a leader's ability to differentiate between self-good and unit-good? Should one build a resistance or stubbornness to the temptations of ambition? Is it correct then to seek opportunities or should one wait to be chosen?[18] Unfortunately, this is the great leadership debate explored when you read the book and reflect on the implications for choosing one style or the other. In reality you are likely to find both Sam and Courtney leadership styles in use … but the true test comes only when a leader is called upon to act.[19]

Which approach is right for a young leader to emulate … the personal leader, or the institutional leader, or both? This struggle can best be summed up by a real Air Force leader, Col John Boyd. Colonel Boyd effectively captured the concept of the difference between the selfless servant and the self-serving leader with one question he would ask all of his new officers. As Boyd stated,

> One day you will come to a fork in the road. And you're going to have to make a decision about what direction you want to go. If you go that way you can be somebody. You will have to make compromises and you will have to turn your back on your friends. But you will be a member of the club and you will get promoted and you will get good assignments. Or you can go that way and you can do something—something for your country and for your Air Force and for yourself. If you decide to do something, you may not get promoted and you may not get the good assignments and you certainly will not be a favorite of your superiors. But you won't have to compromise yourself. You will be true to your friends and to yourself. And your work might make a difference. To be somebody or to do something. In life there is often a roll call. That's when you will have to make a decision. To be or to do? Which way will you go?[20]

So what is the point of this story? What are the takeaways? How should you respond to these challenges? Can you be somebody AND do something? Only each individual can answer these questions. Which brings us back to the original question: are you a Sam or a Courtney?

Notes:

1 This article first appeared in the Malmstrom AFB and F. E. Warren AFB papers as Sq/CC commentaries in the fall of 2007. We have provided examples in the footnotes to provide the reader additional perspectives and commentary.

2 Edgar F. Puryear, *American Generalship—Character is Everything: The Art of Command* (Novato, California: Presidio Press, 2000), 1.

3 Quote from General Charles C. Krulak, former commandant, USMC found at: http://www.once-an-eagle.com/.

4 Roger H Nye, *The Challenge of Command: Reading for Military Excellence* (New York: Berkley Publishing Group, 1986), 2.

5 Ibid., chapter 1.

6 Ken Blanchard and Phil Hodges, *The Servant Leader* (Nashville: Countryman, 2003), 15, 17. According to Ken Blanchard and Phil Hodges, "Whenever we have an opportunity or responsibility to influence the thinking and the behavior of others, the first choice we are called to make is whether to see the moment through the eyes of self-interest or for the benefit of those we are leading." They go on to ask the question, "Am I a servant leader of a self-serving leader?"; Maj Gen Perry Smith (USAF, retired), "Learning to Lead Part 1 and 2," govleaders.org, 1997, http://gov-

In reality you are likely to find both Sam and Courtney leadership styles in use … but the true test comes only when a leader is called upon to act.

leaders.org/genpsmith.htm. Smith adds, "Be a Servant Leader. Too many leaders serve their ambitions or their egos rather than their people."; Andy Andrews, *The Traveler's Gift: Seven Decisions that Determine Personal Success* (Nashville, Tennessee: Nelson Books, 2002), 49, 50. Andrews had the following to say about servant leadership, "I will seek wisdom. I will be a servant to others. A wise man will cultivate a servant's spirit, for that particular attribute attracts people like no other. As I humbly serve others, their wisdom will be freely shared with me." Additionally, he said, "I will become a humble servant. I will not look for someone to open my door—I will look to open the door for someone."

[7] *American Generalship—Character is Everything: The Art of Command*, 160, 158, 169 respectively. Generals Bradley, Patton, and Ridgeway all offer perspectives on lifelong learning. According to Bradley, "You first study the theoretical handling of troops; you study the principles of war and the principles of tactics and how certain leaders applied them. You are never going to meet with that exact situation, but when you know all these principles and how they were applied in the past, then when a situation faces you, you apply those principles to your present situation and hope you come up with a good solution. I think the study of military history, and what the great leaders did, is very, very important for any young officer in developing this quality." Patton stated, "To be a successful soldier you must know history. Read it objectively, dates and even minute details of tactics are useless. What you must know is how man reacts. Weapons change, but the men who use them change not at all. To win battles you do not beat weapons, you beat the soul of every man." Ridgeway added, "A man by himself can have but a very limited experience. So you've got to draw on the experiences of others, both in reading and in talking to men who have made their names in combat, who have demonstrated superior leadership."; Ibid., 85. With regard to intuition or the gut call in decision-making, General Bradley also has this to say: "My theory is that you collect information, little bits of it, and it goes into your brain like feeding information into a 1401 IBM calculator. It's stored in there, but you are not conscious of it. You hear some of it over the phone, you see some of it on the map, in what you read, in briefings. It is all stored in your mind, then suddenly you are faced with a decision. You don't go back and pick up each one of the pieces of information, but you run over the main items that are involved and the answer comes out like when you push the button on an IBM machine. You have stored up this knowledge as it comes in and when you are suddenly faced in battle with a situation needing a decision, you can give it."

[8] US Department of Defense, remarks to Air War College, delivered by Secretary of Defense Robert M. Gates, Maxwell, Alabama, 21 April 2008, http://www.defenselink.mil/speeches/speech.aspx?speechid=1231. Secretary of Defense Robert M. Gates stated the following: "Dissent is a sign of health in an organization, and particularly if it's done in the right way and respectfully and so on. But people who dissent, who take a different view, who kind of are orthogonal to the conventional wisdom are always at risk in their careers, just like [Colonel John] Boyd was. And so figuring out – Boyd couldn't have done what he did unless senior officers, at least one or two, were looking out for him."

[9] George Grant, *The Courage and Character of Theodore Roosevelt: A Hero Among Leaders* (Cumberland House Publishing, Inc., 1996), 112, 120, 139. Teddy Roosevelt offers some valuable insights here: "The man who knows the truth and has the opportunity to tell it, but who nonetheless refuses to, is among the most shameful of all creatures." "My success so far has only been won by absolute indifference to my future career." "It is not always easy to keep the just middle, especially when it happens that on one side are corrupt and unscrupulous demagogues, and on the other side corrupt and unscrupulous reactionaries."; Paul Yingling, "A Failure in Generalship," *Armed Forces Journal*, May 2007; Lt Col Paul Yingling adds the following thoughts: "The general who speaks too loudly of preparing for war while the nation is at peace places at risk his position and status … A military professional must possess both the physical courage to face the hazards of battle and the moral courage to withstand the barbs of public scorn … It is unreasonable to expect that an officer who spends 25 years conforming to institutional expectations will emerge as an innovator in his late forties."; Fred Kaplan, "Challenging the Generals," *New York Times Magazine*, 26 August 2007.

[10] Anton Myrer, *Once An Eagle* (New York: Harper Collins Publishers, 1968), 621.

[11] "Learning to Lead Part 1 and 2." Smith goes on to write, "Serve, Don't Humor the Boss. Too many leaders see their big tasks as keeping their bosses happy, getting to the bottom of the in-box, or staying out of trouble. That is not what leadership is all about. Leadership is serving the mission and serving your people."

[12] *American Generalship*, 203, 188. Some officers in our Ar Force seek out positions that seem to guarantee fast advancement. To those officers, I would submit that the opportunity to learn should be one's number 1 priority rather than what the perceived reward will be at the end of the assignment. As General LeMay once told his aide, "Your first priority is to learn and the second is to serve and don't ever mix those two up." Eisenhower offered his perspective on the value of positions close to senior leaders when he said, "How does one develop as a decision-maker? Be around people making decisions."

[13] Stephen Ambrose, *Citizen Soldiers: the U.S. Army from the Normandy Beaches to the bulge to the surrender of Germany June 7., 1944 – May 7, 1945* (New York: Simon and Schuster, 1997), 334. In his book, *Citizen Soldiers*, Stephen Ambrose quoted a World War II soldier with the following description of behavior not conducive to strong leadership. The soldier stated, "Chickenshit refers to behavior that makes military life worse than it need be: petty harassment of the weak by the strong; open scrimmage for power and authority and prestige…insistence on the letter rather than the spirit of ordinances. Chickenshit is so called – instead of horse – or bull – or elephant shit – because it is small minded and ignoble and takes the trivial seriously. Chickenshit can be recognized instantly because it never has anything to do with winning the war."

[14] "Learning to Lead Part 1 and 2." Maj Gen Perry Smith stated, "Avoid the Cowardice of Silence. During meetings, so-called leaders often sit on their hands when it is time to raise a hand and speak up. Leadership requires courage – courage to make waves, courage to take on our bosses when they are wrong, and the courage of conviction. Every Robert E. Lee needs a James Longstreet to tell him exactly the way it is."

[15] Jeffrey A. Zink, *Hammer-Proof: A Positive Guide to Values-Based Leadership* (Colorado Springs: Peak Press, 2006), 49. How we lead is as important as the results we achieve with our organizations. As Jeffrey Zink wrote, "The ends don't justify the means. Ends and means must both be justified. How we do what we do is every bit as important as what we accomplish."; Perry M. Smith, *Rules and Tools for Leaders: A Down-to-Earth Guide to Effective Managing* (New York, New York: Berkley Publishing Group, 1998), 35. "Some individuals tend to be more interested in survival, in staying out of trouble, in avoiding extra work, or in being promoted, than in carrying out the mission in as effective a way as possible."

[16] General Charles G. Boyd, Air War College, Air University Graduation, 2006, FreeRepublic.com, http://www.freerepublic.com/focus/f-news/1661858/posts. The following remarks by General Boyd provide useful guidance for action in response to these questions. He said, "Your voice, esteemed and credible though it is, has an effect—is only truly effective—when it is used inside the corridors of the policy formulation process—inside the government you serve. This is a very difficult challenge, made the more so by the subservient nature of your culture. You say sir or ma'am to those senior to you, and while that courtesy has considerable value, it also makes it harder to speak in counter argument to your seniors. You are taught from the beginning of your officer training of the intrinsic merit in the maintenance of civilian control over the military. Acceptance of that subordination doesn't make it easier to tell your superior when he or she is wrong. But this you must do, and if you don't you forfeit the right to criticize the flawed policy your silence helped make possible… I know how hard it sometimes can be to oppose strong willed bosses even when you're certain you are right. You work hard, you have talent and want to advance, and yet you know a vindictive boss can stifle you, or worse, truncate your career. But this is the only professional—indeed, ethical—course available to you. In the autumn of your years, as you reflect on the mark you have left, you will be proudest of those times you took the risk to do the right thing and not the expedient. And you will be most ashamed to recall the times you remained silent when you should have stated your mind… Many of you have already fought, and you will continue to fight—and lead others to fight. Many of you will find yourself in the role of advising civilians who are placed in positions of authority over you. They will know less than you about the science and craft of your profession, they will lack your training and education in this arcane business, yet sometimes hold strong

views about its application. Your task—indeed your responsibility—is to help them make the right decisions. With all the power of persuasion you can muster, and at whatever personal risk you perceive that may require, you must tell your bosses what your professional judgment dictates. It is then—before the decisions are made—that you are most effective, not in the TV studios and on the op-ed pages later, after you failed, or worse, did not try, to alter a bankrupt course of action."

[17] A follow-on question could be: "What if you're a Sam working for a Courtney?"

[18] Ulysses S. Grant, *Personal Memoirs* (New York: Random House, 1999), vi. General Grant provides an answer to this question when he said, "It is the men who wait to be selected rather than those who seek from which we may expect the most efficient service."; Edmund Morris, *The Rise of Theodore Roosevelt* (New York: Random House, 1979) and Edmund Morris, *Theodore Rex* (New York: Random House, 2001). Teddy Roosevelt was also violently against becoming a seeker of office because of the consequences it could have to his faithful service. This is clear when he responded to his aides' question about him becoming president. Roosevelt said, "Don't you dare ask me that. Don't you put such ideas into my head. No friend of mine would ever say a thing like that. You... You... Never. Never. You must never either of you remind a man at work on a political job that he may be president. It almost always kills him politically. He loses his nerve. He can't do his work. He gives up the very traits that are making him a possibility. I am going to do great things here. Hard things that require all the courage, ability, work that I am capable of. But if I get to thinking of what it might lead to...I must be wanting to be president. Every young man does. But I won't let myself think of it. I must not. Because if I do I will begin to work for it. I'll be careful, calculating, cautious in every word or act and so I'll beat myself."

[19] Dick Winters, *Beyond Band of Brothers: The War Memoirs of Major Dick Winters* (New York, New York: Berkley Publishing Group, 2006), 293. Dick Winters who led the "Band of Brothers" counsels us to "Remain humble. Don't worry about who receives the credit. Never let power or authority go to your head … True satisfaction comes from getting the job done. The key to a successful leader is to earn respect—not because of rank or position, but because you are a leader of character."

[20] Grant T. Hammond, *The Mind of War: John Boyd and American Security* (Washington: Smithsonian Books, 2001), 10, 206, 340. Robert Coram, *BOYD: The Fighter Pilot Who Changed the Art of War* (Boston, New York, London: Little, Brown and Company, 2002), 285. Another question Boyd would ask is: "Do you want to be part of the system or do you want to shake up the system?" Grant Hammond had the following to say about so-called mavericks: "We need devil's advocates, nay-sayers, doubting Thomases, those who question our assumptions, ends, means, and costs of the course of action the nation adopts … the trick is to allow the mavericks to exist and to be heard, to select those who have real contributions to make from those who merely complain, to keep a certain amount of in-house criticism and nay-saying as a counterpoise to the routine … taking care of the mavericks is not something the American military does well. Few make it to general officer, and most don't make colonel, deciding to leave rather than continue to get hammered in the effort to create change." With this in mind, it is important that General Matthew Ridgeway stated that his most significant role as Army chief of staff was "to protect the mavericks."; Bob Briner, Ray Pritchard, *The Leadership Lessons of Jesus: A Timeless Model for Today's Leaders* (Nashville, Tennessee: Broadman and Holman Publishers, 1997), 59. Briner and Pritchard add: "A good manager makes the existing system work to his or her advantage; a good leader questions the system, making the changes necessary for improvement."; Perry M. Smith, *Taking Charge: A Practical Guide for Leaders* (Washington DC: National Defense University Press, 1986), 87. Perry Smith provides an interesting description of "adaptors" and "innovators." When discussing problem solving, solutions, policies, organizational fit, and perceived behavior, Smith delivers these descriptors: "Problem solving—Adaptors tend to take the problem as defined and generate novel, creative ideas aimed at "doing things better." Innovators tend to redefine generally agreed problems, breaking previously perceived restraints, generating solutions aimed at "doing things differently." Solutions—Adapters generate a few well chosen and relevant solutions, that they find sufficient but generally fail to contain ideas that break the existing patterns completely. Innovators produce ideas that may not be obvious or acceptable. Pool of ideas can crack intractable problems. Policies—Adaptors prefer well established, structured situations. Best at incorporating new data or events into existing structures or policies. Innovators prefer unstructured situations. See opportunities to set new structures or policies with attendant risk. Organizational fit—Adaptors are essential for ongoing functions. May have trouble establishing role in time of needed change. Innovators are essential in time of change or crisis. May have trouble applying themselves to ongoing organizational needs. Perceived behavior—Adaptors are seen by innovators as sound, conforming, safe, predictable, relevant, inflexible, wedded to the system, intolerant of ambiguity. Innovators are seen by adaptorsas unsound, impracticable, risky, abrasive, often shocking their opposites, and creating dissonance.

Lt Col Robert J. Vercher (BS, Auburn University; MA, Webster University; MA, George Washington University; MMOAS, Air University) is the commander, 12th Missile Squadron, Malmstrom AFB, Montana. During his career, he has held a wide variety of leadership positions in space/missile operations. He served as an ICBM crew commander, crew instructor, senior standardization/evaluation crew commander, Delta II chief of training, and Emergency War Order instructor. He also served on the US Strategic Command, HQ Air Force, Air Force Space Command, and 20th Air Force staffs as an ICBM strike planner, USAF intern, aide de camps, executive officer, and command lead, space superiority command and control. Colonel Vercher is a command space/missile officer, and a fully qualified joint specialty officer.

Lt Col Andrew S. Kovich (BS, Bowling Green State University; MS, Central Michigan University; MMOAS, Air University) is the commander, 90th Maintenance Operations Squadron, F. E. Warren AFB, Wyoming. During his career, he has held a wide variety of leadership positions in space/missile operations and maintenance. He served as an ICBM crew commander, crew instructor, senior standardization/evaluation crew commander, maintenance flight commander, Defense Support Program flight commander, chief, standardization/evaluation, and operations officer. He also served on the US Strategic Command and 20th Air Force staffs as an ICBM strike planner, policy/doctrine officer, executive officer, and chief, Emergency War Order Plans and Procedures. Colonel Kovich is the author of "USAF Relevance in the 21st Century: A First-Quarter Team in a Four-Quarter Game," published in the July-August 2006 edition of *Military Review*; "20th Air Force: Developing 21st Century Strike Planners" and "Sustaining Nuclear Expertise in AFSPC: A Way Ahead for ICBM Maintenance and Operations" published in August/November 2007 editions of *High Frontier*.

Colonel Kovich and Colonel Vercher were the recipients of the Best Crew Award and the Blanchard Trophy at the 1994 Guardian Challenge Competition and the 1995 Thomas S. Power Award for best missile crew in the US Air Force.

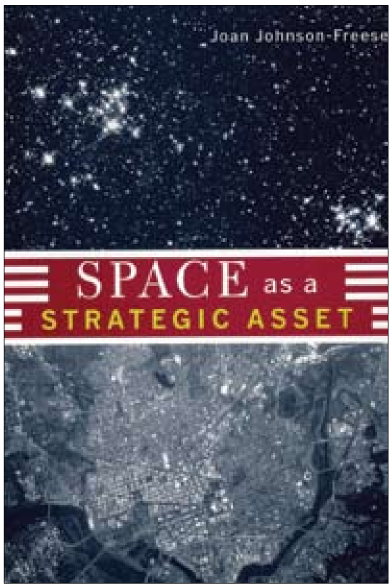
Book Review

Space as a Strategic Asset

Space as a Strategic Asset. By Joan Johnson-Freese. New York: Columbia University Press, 2007. Notes. Index. Pp. 304. $46.50 Hardcover ISBN: 0231136544.

When an author admits up front that she did not write the book she wanted to (p. viii), it certainly is harder on the reviewer. But when a book is as well written as this one, it inevitably generates as many questions as it tries to answer, thus furthering collegial thinking, and in the end, advancing knowledge. This book is a considered approach to the problem of space strategy, looking at many aspects of the national space programs in an attempt to develop a strategic plan for success in space. Whether you believe that space is a strategic asset or a domain of warfare in the same way that air, land, sea, and cyberspace are, it's the strategic-level approach to space that makes this book valuable. Additionally, whether or not you agree with the author's prescription for national space, it is important for space professionals to get out of their stovepiped cubicles and think about the broad strategic meaning to the domain in which we operate. This full spectrum approach to space strategy, not focused on the often-tactical details of budget and technology, is a welcome approach to the broad questions facing the national space programs.

The premise of this book is that many current space policies are failing because they do not serve the national interest and need to be reconsidered using a wide-ranging approach (p. vii). Further, the author argues that the US has no comprehensive space strategy and that the US needs a national space strategy focused beyond military space programs (p. ix). The official reason for the president's space vision is exploration but it will fail, in the author's opinion, because it is not a plan (p. 79). However, it is unlikely the US will achieve the lofty goal of a comprehensive national space plan in 2008 with a program the size and shape of current US programs. The current space program is far bigger than in 1960 when the national space program, indeed the US government, were far smaller and the threat far more measurable. It may be easier for a program the size and shape of India's or China's to achieve a comprehensive national plan for space that the author suggests the US needs.



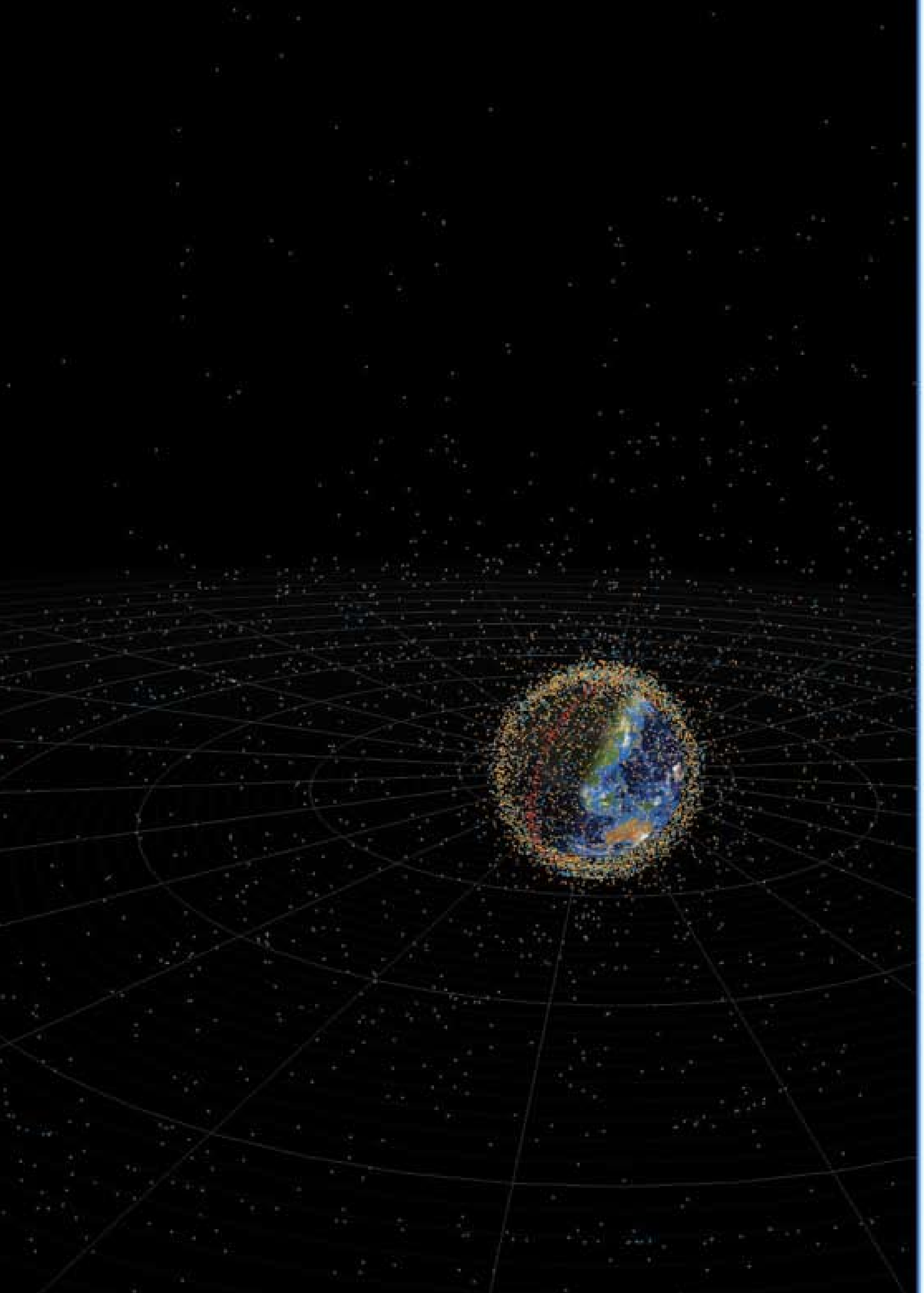
The author's recommendation for a successful space strategy is spelled out after several chapters of building a case. In the end, therefore, the author argues that "space security must be redefined in the US to ease the tension of the security dilemma and preserve American space leadership in the military, civilian, and commercial domains" (p. 238). To achieve that goal, the book suggests that the US needs to resolve the security dilemma and maintain military space leadership; move toward strategic stability (i.e., prevent technology from driving strategy [p. 243]); create confidence-building measures (e.g., space surveillance data for all); write the rules of the road on an international scale; "truly and realistically" internationalize manned space programs; and maintain commercial leadership by refining and redefining export-control regimes. Therefore, the reviewer would like to suggest a novel way of reading this book. After reading the first chapter, skip forward and read the last, spoiling the ending, so to speak. Then read the intervening chapters and finally reread the last, prescriptive chapter.

The author wants to use the US space program to enhance national "soft" power by using the familiar DIME approach to international relations. This is in part an appeal to reinvigorate the manned space program, an historical font of US soft power, where the author fears we are ceding our leadership (p. 55). Indeed, the author argues, the impact not just on science and engineering leadership, but "imagination and vision" (p. 80) could be disastrous. However, if it took the space race to get to the moon first, what will it take to stare down China's incremental approach to space? As the author points out, "China has seen the advantage that the US military reaped from space and seeks to enhance its own position" (p. 209). So, the author suggests, perhaps it is time for "another détente effort, to turn competition into cooperation" (p. 19), though it may be much more difficult to achieve détente in today's multilateral, hypertechnological space environment.

Additionally, the soft power approach is also an attempt to convince the reader that the US cannot contain space technology and must rein in space control and force application programs rather than seeing all space activity through a lens of hard power (p. 25). By limiting that which is exported, the author also argues, the US is limiting "the aerospace industry, on which the US military and economy depend," thus committing "strategic suicide" (p. 168). In this way, the US, unable to monopolize space technology, will not have to put the technological genie back in the bottle after it has escaped (p. 26) and will hold onto the leadership position it has held since Apollo (p. 52).

A significant challenge of this book is the timing, as the author admits (p. ix), which unfortunately, leads to the inevitable question that violates the old adage about book reviewing but needs to be asked: "Would the conclusions of this book be any different because of the 2007 Chinese antisatellite weapon launch or the 2008 US satellite shootdown? Has anything changed in the conditions that led to the author's conclusions? Has anything changed in the discussion of weaponization of space (p. 201)?" Regardless of your final agreement with the author's conclusions, for its grand approach to the problem of US space strategy this book is highly recommended to space professionals who are, or will be, strategic thinkers.

Lt Col David C. Arnold is the deputy commander of Thule Air Base, Greenland, and the author of Spying From Space: Constructing America's Satellite Command and Control Networks (Texas A&M, 2005).



We are interested in what you think of the ***High Frontier*** Journal, and request your feedback. We want to make this a useful product to each and every one of you, as we move forward to professionally develop Air Force Space Command's space and missile workforce and stimulate thought across the broader National Space Enterprise. Please send your comments, inquiries, and article submissions to: HQ AFSPC/PA, *High Frontier* Journal, 150 Vandenberg St, Ste 1105, Peterson AFB, CO 80914-4020, Telephone: (719) 554-3731, Fax: (719) 554-6013, Email: afspc.pai@peterson.af.mil, To subscribe: hard copy, nsage@colsa.com or digital copy, http://www.af.mil/subscribe.

U.S. AIR FORCE

AFSPC/PA
150 Vandenberg St.
Ste 1105
Peterson AFB, CO 80914
Telephone: (719) 554-3731
Fax: (719) 554-6013
For more information on space professional development visit:
www.peterson.af.mil/spacepro